Economics of Sustainable Energy in Agriculture

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Economics of Sustainable Energy in Agriculture

Edited by

Ekko C. van Ierland
Professor of Environmental Economics,
Wageningen University, The Netherlands

and

Alfons Oude Lansink
Associate Professor Farm Management,
Wageningen University, The Netherlands

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Table of Contents

Chapter 1 Sustainable energy in agriculture: issues and scope
Alfons Oude Lansink, Ekko C. van Ierland and Gustavo Best 1

Part I Energy use efficiency and intensity in agriculture

Chapter 2 Better management can improve the efficiency of indirect energy
Tanja J. de Koeijer, G.A. Ada Wossink, A. Bert Smit and S. (Bas) R.M. Janssens 11

Chapter 3 Energy investigations of different intensive rape seed rotations – a German case study
Johannes Moerschner and Wolfgang Lücke 27

Chapter 4 Modelling energy saving technology choices in Dutch glasshouse horticulture
Kyosti Pietola and Alfons Oude Lansink 41

Chapter 5 Energy intensity decomposition in EU agriculture, using a demand analysis
Joaquín A. Millan 57

Part II Biomass production: Technical issues

Chapter 6 Energy use efficiency in biomass production systems
Sanderine Nonhebel 75

Chapter 7 Yield increases of the biomass crops *Salix viminalis* and *Miscanthus x giganteus*: A look to the future
Leo M. Vleeshouwers 87

Part III Biomass production and land use

Chapter 8 Agricultural reference systems in life cycle assessments
Nicolai C. Jungk, Guido A. Reinhardt and Sven O. Gärtner 105

Chapter 9 Energy from hemp? Analysis of the competitiveness of hemp using a Geographical Information System
Claus Brodersen, Klaus Drescher and Kevin McNamara 121

Chapter 10 The role of forestry in climate change and sustainable energy production
G. Cornelis van Kooten, Emina Krcmar and Peter J. Graham 135

Part IV Agriculture and other sources of sustainable energy

Chapter 11 Modelling water resource allocation: A case study on agriculture versus hydropower production
Jorge Bielsa and Rosa Duarte 157

Chapter 12 Development and implementation of the Danish centralised biogas concept – financial aspects
Kurt Hjort-Gregersen 177

Part V Scenarios and policies for sustainable energy

Chapter 13 Can organic farming help to reduce national energy consumption and emissions of greenhouse gasses in Denmark?
Tommy Dalgaard, Niels Halberg and Jes Fenger 191

Chapter 14 On renewable energy in rural China
Huang Liming and Ekko C. van Ierland 205

Chapter 15 Determining efficient bio-fuel tax exemption policy in France for greenhouse gas emission abatement
Stelios Rozakis, Jean-Claude Sourie and Daniel Vanderpooten 217

Index 239

Reviewers 245

Contributing Authors 247

Chapter 1

SUSTAINABLE ENERGY IN AGRICULTURE: ISSUES AND SCOPE

Alfons Oude Lansink, Ekko C. van Ierland and Gustavo Best

1. INTRODUCTION

In the coming decades the world faces the challenge to make a transition to sustainable energy use patterns in order to save fossil fuels for future generations and to reduce the negative impacts of burning fossil fuels on the environment. The issue of climate change requires substantial reductions in the emissions of greenhouse gases in the world as emphasised by the Intergovernmental Panel on Climate Change (IPCC 1996; IPCC 2001).

Figure 1.1 shows the evolution of the world's total final energy consumption by fuel type in the period from 1971 to 1999. The International Energy Agency IEA (IEA 1998) expects the world energy demand to grow by 65% between 1995 and the year 2020, as a result of economic growth. Except for nuclear energy, demand for all categories of energy are expected to increase. Oil, solids (mainly coal and biomass) and gas are the dominant energy supply categories today (see Figure 1.2), and are also expected to remain the main sources of energy till the year 2020; hydropower and other renewables will continue to play a modest role.

At present, the world's conventional oil reserves are estimated to be 1 trillion barrels and at current rates of consumption it is estimated that these reserves will not be sufficient to meet the increasing demand by the year 2020 (UNDP 2000). All recent international efforts assessing the environment, including the 1992 Earth Summit in Rio de Janeiro, the IPPC, the UNFCCC and the Commission for Sustainable Development – CSD, refer to the massive consumption of fossil fuels in the aggravation of global environmental problems. The Kyoto Protocol, recently adopted in the context of the Climate Change Convention, calls for a decrease in CO_2 emissions by improving energy efficiency and the use of renewable energy sources.

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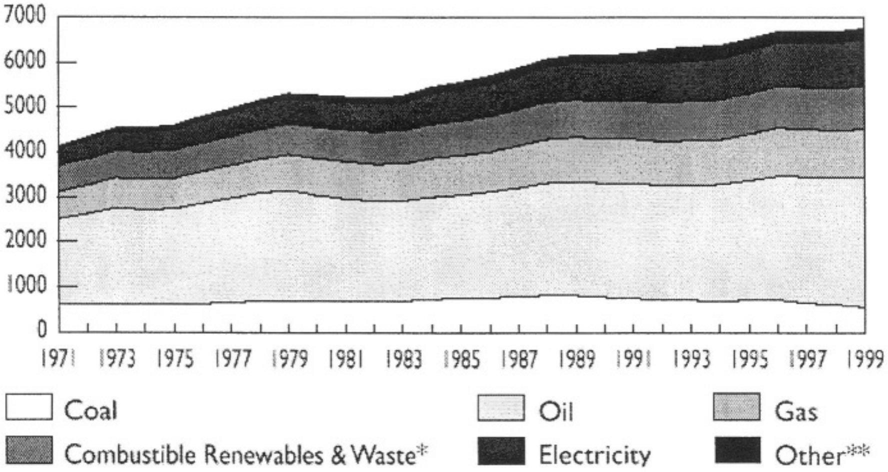

Figure 1.1. World total energy consumption by fuel type (Mtoe)
**Prior to 1994 Combustible Renewables & Waste final consumption has been estimated based on TPES*
***Others includes geothermal, solar, wind, heat, etc.*
Source: IEA (2002)

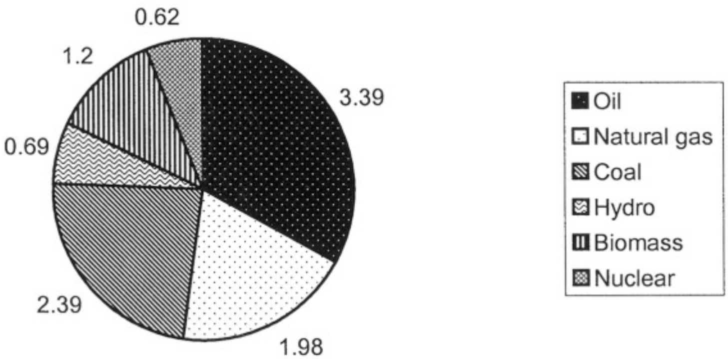

Figure 1.2. World primary energy use by fuel type, 1997 (Gtoe)
Source: BP (1998)

2. RELATION BETWEEN AGRICULTURE AND ENERGY

Agriculture plays a key role in the process of transition towards more sustainable energy use patterns. First, the agricultural sector is itself a user

of energy, not only in primary production of commodities, but also in food processing and distribution of agricultural products. Second, the agricultural sector substantially contributes to energy supply, in particular through the production of biomass, including fire wood, agricultural by-products, animal waste, charcoal, other derived fuels and, increasingly through production of energy crops. The share of biomass in energy consumption differs widely for various regions in the world, ranging from 1% in Oceania, to 47% in Asia (see Figure 1.3). The share of biomass in energy consumption depends on economic structure, the level of income, the availability of land and other energy sources. Most of this consumption is in the form of low efficiency conversion systems with adverse effects on human health and the environment.

Although land is a scarce production factor in Western Europe, it is more widely available in Eastern Europe, the USA and many developing countries. This offers substantial scope for an increase in the production of biomass at relatively low costs. Less productive agricultural areas and land in set aside programmes could contribute to the production of biomass in the USA and some countries of the EU. In many rural areas in developing countries, bioenergy production is already an important agricultural activity.

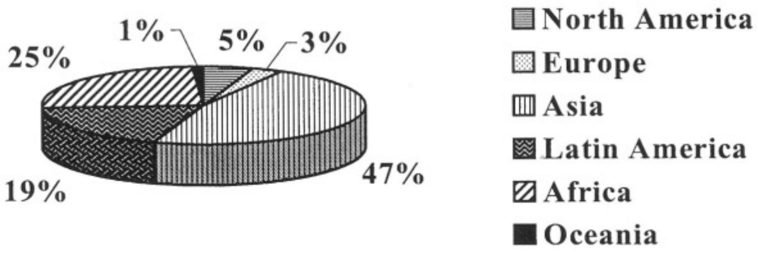

Figure 1.3. 1993 world biomass energy consumption
Source: FAO Various publications

Traditional use of biomass may lead to deforestation and excessive use of natural resources. On the other hand, technological progress is expected to bring more efficient biomass energy production systems and enables new applications such as the production of energy from waste and by products of agriculture.

The Kyoto Protocol and its flexible mechanisms, *i.e.* the Clean Development Mechanism and Joint Implementation have renewed the interest in the role of agriculture in CO_2 mitigation. Storage of carbon in forests and the use of biofuel crops may reduce net emissions of greenhouse gases to the atmosphere and mitigate global warming. However, the storage capacity is small compared to the tremendous quantities of CO_2 emissions from burning fossil fuels. Moreover, reforestation requires land with alternative uses in e.g. food production, implying that it may adversely affect world food supply. Costs of carbon sequestration differ widely across the world, from a few dollars per ton in developing countries, to several hundreds of dollars per ton in developed countries.

The experience with energy crops in agriculture is still very limited and most of what is known owes more to traditional agricultural techniques. Nevertheless, some studies have indicated that the potential replacement of fossil fuel by energy crops in the tropics alone can be as high as 150 to 510 Tg (150-510 Mt) C/year. In temperate zones, C offsets could be as high as 80 to 490 Tg C/year. Agro-forestry systems, where trees are grown in combination with food or feed could offset 10 to 50 Tg C/year in temperate zones and between 50 to 200 Tg C/year in tropical regions (Woods and Hall 1994).

3. SCOPE OF THE BOOK

The chapters of this book have been prepared for the conference 'Sustainable Energy: Challenges for agriculture and implications for land use' at Wageningen University, The Netherlands (May, 17-19, 2000). The purpose of this book is to reflect the current state of the art in research on the role of agriculture in energy consumption and energy production. The approaches used in the various chapters in this book are retrospective and prospective, *i.e.* both past and future energy use and production are dealt with. Although the central focus of this book is on economic issues related to energy use and production by agriculture, the book also includes results of multidisciplinary research.

The first section of this book focuses on the efficiency and intensity of energy use in agriculture. In *Chapter 2,* de Koeijer, Wossink, Smit and Janssens investigate the relation between management and energy efficiency for a sample of Dutch cash crop farmers. The results in their chapter suggest that there is considerable scope for improvement of technical efficiency at the farm and crop levels. Furthermore, results show that farmers are more efficiently using indirect energy if they know their

own farm data better and if they are capable of incorporating this information into their fertilisation strategy. In *Chapter 3,* Moerschner and Lücke provide an analysis of energy use, energy intensity and energy productivity of farms with different intensive oil seed rape rotations in Lower Saxony. They find that crop rotations are a critical factor in energy intensity and productivity. Also, they find that a site-specific reduction in farming intensity has ecological advantages and opens interesting potentials for saving (fossil) energy resources. In *Chapter 4,* Pietola and Oude Lansink introduce a dynamic aspect of energy use by modelling investments in energy saving technologies on Dutch glasshouse firms using simulated maximum likelihood. Their results show that the probability to invest in energy saving technologies increases with firm size, energy price and the stock of capital invested in installations; the stock of capital invested in structures (*e.g.* glasshouses) decreases the probability to invest in energy saving technologies. Joaquin Millan concludes part I with *Chapter 5* on an energy intensity decomposition for EU agriculture. The decomposition of input intensities in this study shows that, in general, prices have a very limited contribution to changes in energy intensity, and even less in energy-based input intensity, relative to quasi-fixed inputs and technical change. Another conclusion from this study is that the evolution of energy demand and energy-based intensities in EU agriculture is country specific, thereby limiting the scope for general EU-wide agri-environmental policies.

The second section of this book focuses on technical issues related to biomass production. In *Chapter 6*, Sanderine Nonhebel assesses the resource use efficiency of different biomass production systems in the Netherlands and Portugal. The results in her study show that low-input systems are only efficient with respect to their use of fossil energy and that their efficiency is very poor regarding the use of other inputs. Furthermore, this study shows that the net energy yield (harvested energy – fossil energy required for the production) is much higher in the high-input systems. In *Chapter 7*, Leo Vleeshouwers makes predictions of future yield increases of two biomass energy crops, *i.e. Salix viminalis* and *Miscanthus × giganteus.* In the next 20 years, due to improved breeding and crop management, stem growth may increase by 1.2 % annually to 12.0 t d.m. ha^{-1} y^{-1} in *S. viminalis,* and by 1.41 % annually to 13.0 t d.m. ha^{-1} y^{-1} in *M. × giganteus.* The estimates found in this study are lower than earlier findings in the literature.

The third section of this book discusses various aspects of the relation between land use and biomass production. Jungk, Reinhardt and Gärtner focus in *Chapter 8* on the role of agricultural reference systems in life cycle assessments. The reference system defines the alternative use of

cultivated land area, if not used for the investigated product. Their example of the production of rapeseed methyl ester (RME) for biodiesel demonstrates that the agricultural reference system may have a significant effect on the results of a life cycle analysis. In *Chapter 9,* Brodersen, Dresher and McNamara demonstrate the usefulness of a Geographical Information System for analysing the competitiveness of hemp. Their research shows that the use of hemp as an energy resource is more favorable in counties in East Germany. Nevertheless, under current prices hemp cannot compete with other fast growing plantations or with oil and gas. In *Chapter 10,* van Kooten, Krcmar and Graham conclude the third part of this book with an analysis of the role of forestry in climate change and sustainable energy production. These authors conclude that previous research efforts have mainly focused on the role of forests in atmospheric CO_2, whereas the information about the role of other potential sinks for C is still very limited. Furthermore, the authors provide an attempt to fill up the large gap in information about the potential for bioenergy to replace use of fossil fuels.

Part four of this book deals with the relation between agriculture and other sources of sustainable energy. In particular, *Chapter 11* of Bielsa and Duarte provides a model of water resource allocation in Spain with a focus on the relation between agriculture and hydropower production. The application of the model to a specific case confirms the potential of flexible and tradable water rights for improving water allocation compared to a system based on administrative rules. *Chapter 12* of Hjort-Gregersen shows that biogas has a good potential to contribute to the solution of environmental problems and the production of energy in Denmark.

The fifth and final part of this book focuses on future scenarios studies and the scope for economic policies in enhancing sustainable energy production and use in agriculture. In *Chapter 13*, Dalgaard, Halberg and Fenger present the results of three national scenarios implying a full conversion to organic agriculture. The authors show that emission of greenhouse gases decreases under each of the scenarios. In *Chapter 14* Liming and van Ierland deal with projections for future production and demand of renewable energy in rural China. Furthermore, this chapter discusses a number of problems that are expected in meeting the rapidly increasing demand for energy in China. The authors conclude that renewable energy will be an important energy source in rural China and that it is essentail to develop sustainable biomass systems to fulfil this role. The book concludes in *Chapter 15* with a study by Rozakis and Vanderpooten who use a multi-criteria optimisation model to determine optimal tax credit policies for greenhouse gas abatement. The authors show that the current tax credits are well below the optimal tax credits

determined by their model, suggesting there is considerable scope for improvement of the current tax policies.

The studies in this book clarify that energy supply will face substantial changes in the coming decades. Carbon sequestration and production of biomass will gain momentum as a result of climate change policies. The tendency for energy efficiency improvement will continue on the basis of autonomous technological change and most likely on price induced incentives. Which energy supply and biomass systems will prevail will depend on local circumstances, technological development and its impact on the cost structure. Also, agricultural and environmental policy measures (set aside arrangement, subsidies, tax exemptions, energy taxes) and the potential for emission offsets through biomass systems may influence the adoption of biomass production by agriculture.

In the coming decades, agriculture in developed and developing countries faces new challenges and opportunities as a result of the Kyoto protocol and its flexible mechanisms. Of key importance will be the flexibility of agriculture to react on these new opportunities.

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Part I

Energy use efficiency and intensity in agriculture

Chapter 2

BETTER MANAGEMENT CAN IMPROVE THE EFFICIENCY OF INDIRECT ENERGY

Tanja J. de Koeijer, G.A. Ada Wossink, A. Bert Smit and S. (Bas) R.M. Janssens

1. INTRODUCTION

This chapter examines whether differences in the efficiency of the use of indirect energy of Dutch arable farms are attributable to differences in management. To do so, Data Envelopment Analysis (DEA) was used to assess farm-specific efficiency scores for fertilisers — the input most important for energy conservation in crop farming. Next, using the concept of strategic management, the quality of fertilisation management was assessed for a sub-sample of the farms used in the DEA analyses. To assess the farmers' mission, their major objectives were measured. The quality of the external analysis was evaluated by questions about the Mineral Accounting System (MINAS) that will become mandatory for Dutch arable farms by 2001. The internal analysis was evaluated by comparing farmers' opinions on shortcomings in their fertilisation management with the shortcomings indicated by an interactive simulation model. The average technical efficiency score of indirect energy use at farm level was 61%, suggesting scope for improvement. Average efficiency scores for individual crops varied between 33% and 51%. Significant positive correlations were found with the gross margins realised for winter wheat and potato, making it interesting for farmers to improve their fertilisation efficiency. The results indicate that if farmers knew their own farm data better and were able to incorporate this information into fertilisation strategy, they could improve their indirect energy efficiency.

One of the prerequisites for reducing energy use is the efficient use of inputs characterised by relative high energy values. An energy value covers both direct energy for its production and the additional indirect energy required for processing and transport of a specific input. In crop

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production, synthetic pesticides and fertilisers are responsible for most of the total consumption of indirect energy (Clements *et al.* 1995). Earlier research (De Koeijer *et al.* 2001) showed that the Dutch arable farmers differ significantly in efficiency of fertiliser and pesticide application. Moreover, the differences in efficiency among farmers were found to persist within years (over fields) and also between years. As physical conditions could be assumed to be fairly similar for all farmers in the data set analysed it was concluded that differences in efficiency must be mainly the result of differences in farm management. The central issue examined in this chapter is whether differences in the efficiency of indirect energy use could be explained by differences in farm management. With this insight, keys could be found to improve management in order to reduce the use of indirect energy.

Management is often mentioned as an important factor in explaining efficiency but little has been done to actually analyse the relation between management and the efficiency realised. The efficiency literature often explains the relation between management and technical and/or economic performance by personal aspects such as 'level of education' and 'experience or age' (for an overview see Rougoor *et al.* 1998: 266). These aspects are relatively easy to measure but cover only a small part of the total management concept. Recently, methods from experimental economics have been put forward as offering possibilities for analysing the behaviour of decision-makers. Experimental economics is a means to benefit from the strength of field experiments (such as control of intervening variables) and to overcome some of their practical limitations (such as high money and labour requirements) (Verstegen *et al.* 1998). An off-farm economics experiment seems to be particularly appropriate for effective analysis of all aspects of management capacity in terms of technical performance.

The reduction of technical inefficiencies has always attracted interest because of its financial benefits, given the environmental arguments to reduce emissions and waste, but it is now an even more attractive option. Insight into the relation between technical efficiency and sustainability is needed in order to know whether improving the technical efficiency is a relevant factor for improving sustainability. Quantification of the technical and sustainable inefficiencies allows a given firm's performance to be studied by comparing it with other firms (Tyteca 1997). Only recently has the measurement of environmental efficiency received attention in de literature. Tyteca (1996; 1997) presents an overview of the studies in this field. Also recently, several studies have been published on environmental efficiency in agriculture (see *e.g.* Fernandez-Cornejo 1994; Piot-Lepetit *et al.* 1997; Reinhard *et al.* 1999). These efficiency studies

generally focus on pesticide and fertiliser use. Research on energy use in agriculture has been limited to productivity analyses at the crop (Clements *et al.* 1995) or sector level (Uhlin 1999).

Against this background, the present chapter contributes to the literature by (1) assessing differences in the efficiency of indirect energy use among farmers, and (2) explaining these differences through differences in management. With this insight, weak aspects in the management of individual farms can be identified, which is the first step for farmers and/or their advisers in the process of improving farm management. In the next section, the theoretical concept of management is elaborated. Then, the management concept is operationalised, data are analysed and the methods used are described. Finally, the method and results are evaluated and conclusions are presented.

2. THEORETICAL BACKGROUND

Strategic management can be defined as the art and science of formulating, implementing and evaluating decisions that enable a company to achieve its objectives (David 1999). Key terms in strategic management are: mission statements, external analysis, internal analysis, synthesis, strategies, annual objectives and strategies (David 1999). A firm's mission can be seen as the abstract representation of the objectives of the entrepreneur. The internal analysis identifies the strengths and weaknesses of the firm (which could be a farm) in relation to the objectives of its manager. The external analysis identifies the opportunities and threats from the environment of the farm in relation to the farmer's objectives. The synthesis of the external and internal analyses with the mission of the firm results in a firm strategy (Huirne 2000). Implementation of the strategy in practice will be the result of the implementation of the annual objectives and strategies, *i.e.* the tactics and the operations: day-to-day decisions. The concept of strategic management is appropriate for analysis of the total complex of variables characterising farmers' management with respect to technical performance.

Although not explicitly mentioned in the literature on strategic management, the cycle consisting of the mission (objectives), external and internal analysis and the synthesis resulting in a strategy is also repeated at the levels of tactical and operational management. Decisions at these levels are also affected by the opportunities and constraints imposed by the environment and the strengths and weaknesses of the farm — although these decisions are derived from the objective set at the tactical and operational management level, respectively. Given this similarity, we

consider the *concept* of strategic management to be a useful approach for analysing the decision-making process at the tactical and operational levels too. At the tactical management level, the *concept* of strategic management can help to elucidate the personal factors that affect the selection of production techniques in a given farm organisation and external environment. The concept can provide relevant insights into the relation between management aspects and the farm's technical and economic performance.

3. METHODS AND MATERIAL

3.1 Methods

A workshop with nine arable farmers for whom bookkeeping data were available from the Dutch Farm Accountancy Network (FADN) was organised in which the following elements of strategic management were measured: the firm mission, the external analysis, the internal analysis and the production technique. These elements were made operational by relating them to a specific case, the fertilisation legislation in the Netherlands known as MINAS (Mineral Accounting System). MINAS assesses and taxes overuse of nitrogen (N) and phosphorus (P) and will become mandatory for crop farms by 2001. MINAS was chosen as a case study because in this accounting system efficient use of nitrogen is crucial. Nitrogen is also the most important factor in the indirect energy use by arable farmers in The Netherlands (IMET 1994). The amount of energy required to manufacture the commonly applied nutrients indicates the relevance of nitrogen: 1 kg N, 1 kg P_2O_5 and 1 kg K_2O require 38.6 MJ, 3.3 MJ and 2.5 MJ, respectively (IMET 1994).

An interesting question with regard to the introduction of MINAS is whether a farmer synthesises his mission with internal and external analysis, and comes up with an optimal fertilisation tactic. In order to measure the quality of the farmer's synthesis, the participants were asked twice to indicate their fertilisation tactic with the introduction of MINAS. However, the second time they were asked to enter their fertilisation plan into an interactive simulation model which used their farm data and enabled them to optimise their fertilisation tactic by trial and error. By comparing the simulated fertilisation tactic, yield levels and nutrient surpluses with those previously indicated by the farmers, an indication was obtained about the quality of the synthesis. Next Data Envelopment Analysis (DEA) was used to quantify the relative energy efficiency for each farmer. The relationships between the management aspects of the

farmers measured in the workshop and the efficiency scores measured with DEA were analysed with Spearman's rank correlation method.

3.2 Workshop, management indicators and objectives

Data on the elements of the concept of strategic management were obtained as follows: each farmer's mission was assessed by measuring his major objectives and his strategies for achieving these objectives. The farmers were asked to assign in total 7 points to 3 out of 10 goals. They were allowed to add any major objectives that had not been listed. To analyse the relationship between the mission and the energy efficiency the economic character of the mission was assessed by totalling the number of points attributed to objectives that were purely economic.

For the measurement of the intensity of the external analysis, the farmers were asked about their knowledge of and attitude to MINAS. During 2000, all Dutch arable farmers were able to participate in MINAS pilot projects on a voluntary basis in order to familiarise themselves with the system. The workshop attendees were asked if they had done so and if they had attended information meetings. Furthermore they had to answer questions on the accounting rules used in MINAS: 1) Is the yield level of a crop relevant? 2) Are the crop species relevant? and 3) Is it relevant to register possible positive results (*i.e.* the amount of nitrogen that could have been applied additionally without exceeding the norm above which tax has to be paid) on the nutrient balance sheet? The score for the external analysis ranged from 0 (no correct answer) to 3 (all answers correct).

The intensity of the internal analysis was measured by asking farmers to indicate no more than three major weak aspects of their fertilisation management with regard to MINAS. Whether the mentioned aspects were indeed major bottlenecks was assessed by expert judgement of their current fertilisation practices. The score ranged from 0 (inappropriate bottlenecks indicated) to 2 (correct bottlenecks indicated).

A farmer's synthesis of his mission, internal and external analysis should result in a fertilisation tactic. Therefore, asking the farmers how they would adapt their fertilisation tactic to MINAS assessed the synthesis. The quality score ranged from 0 (in the case of opposite trends) to 2 (the trends indicated agreed with the simulation results).

3.3 Interactive simulation model

In the workshop, the farmers were asked to enter their fertilisation tactic into an interactive simulation model, so that they could analyse the effects

of their fertilisation management selected for the situation of their own farm. It is a very complex matter to analyse how the farmers synthesise their personal motives and drives with the external opportunities and threats they perceive and the strengths and weaknesses of their farm into specific management measures. Each farmer has a unique set of personal and farm-specific characteristics, and the complex production process is an extra complicating factor. This diversity can be taken into account with an interactive simulation model (Baarda 1999). Each individual farm can then be visualised by the computer using data from the FADN, so each farmer makes decisions for his specific situation.

The model registers nutrient surpluses, costs and returns at both crop and farm level. Included in the simulation model are the most important relations between nutrient level and crop yield; it is therefore an appropriate tool for analysing the yield and nutrient surplus effects of different fertilisation tactics. The farmers were able to adjust their fertilisation tactic on the computer by adjusting the level of fertiliser application, the type, period and manner of manure applied and the use of catch crops in order to achieve higher yields, higher margins and/or lower taxes on surpluses.

The data on input-output relations used in the simulation model were derived from agronomic insights and experiments from agronomic research institutes. The basic assumption was that optimal yield would be realised if the amount of nitrogen and phosphorus applied equalled the fertiliser recommendations (Van Dijk 1999). At higher nutrient doses, yield levels would not increase and at lower doses, yields would fall.

The farm-specific output levels and the input and output prices are derived from the FADN. These data were normalised for prices and influences of weather. The model has been tested on 10 farmers from the Dutch Central Clay Area in an earlier workshop. The reactions of these farmers were very positive; they felt very comfortable with the basic assumptions and the input-output relations included. The content of the simulation model was not modified, except for some modifications to improve its user friendliness.

3.4 DEA analysis

DEA was employed to quantify the efficiency of nitrogen applied to Dutch arable farms in the Southwest of the Netherlands. The basic standpoint of productive efficiency, as applied in DEA, is to individually compare a set of decision-making units (farms). DEA constructs a frontier representing the most efficient farms and the method simultaneously calculates the

distance to that frontier for the individual observations. The frontier is piecewise linear and is formed by tightly enveloping the data points of the observed 'best practice' activities in the observations, *i.e.* the most efficient farms in the sample. DEA uses the distance to the frontier as a measure of efficiency. Relative performance to the frontier provides a score for each farm from 0 (worst performance), to 1 (best performance). For a review of the general advantages of the DEA technique over other, parametric, approaches see, for example, Seiford and Thrall (1990) and Färe *et al.* (1994; 1996).

In this chapter, we consider the technical efficiency (TE) of a farm to be represented by the ratio of the best technical performance in the data set to the technical performance of that particular farm. Assuming that for sustainability, the use of indirect energy should be minimised, we used an input-oriented DEA model aiming at minimising the input level given the output level. Following the general approach, we assumed that the input is strongly disposable, *i.e.* the input level can be reduced at no cost. The DEA model used is described in the equation set (2.1a)-(2.1e).

$$\text{Minimise} \quad \Phi_j \qquad (2.1a)$$

$$\text{subject to} \quad Yv_j \geq y_j \qquad (2.1b)$$

$$Bv_j \leq b_j \Phi_j \qquad (2.1c)$$

$$\Sigma v_j = 1 \qquad (2.1d)$$

$$v_j \geq 0 \qquad (2.1e)$$

where Φ_j is the Farrell-Debreu measure of efficiency of the j-th farm; Y is a $p \times n$ matrix of p outputs produced by the n farms; v_j is the intensity vector of the weights attached to the n farms for the construction of the virtual comparison unit for farm j; y_j is a $p \times 1$ vector of quantities of output produced by farm j; B is a $m \times n$ matrix of m inputs used by the n farms, and b_j is the vector of these inputs for farm j.

The efficiency of the n farms is assessed by solving n LP models, in which the vectors y_j and b_j are adapted each time another farm j is considered. From constraint (2.1c) follows that Φ_j can never exceed unity. A solution for Φ_j that is less than unity indicates that a weighted combination of other farms in the sample exists that produces at least the same amount of output but with fewer inputs. Constraint (2.1d) is added because variable returns to scale are assumed.

In this chapter, technical efficiency (TE) is calculated according to model (1) using Onfront (Färe and Grosskopf 1998). The input that is taken into account is measured as the amount of indirect energy use in chemical

fertiliser (giga joule, GJ). The output is measured as total revenue in Dutch guilders (DFL[1]) for the crops produced on the farm concerned. Differences in energy efficiency at farm level could be caused by (1) differences in the cropping plan and by (2) differences in output prices. To avoid these disturbing effects, efficiency scores at crop level were assessed, additionally. At crop level the efficiency scores for the indirect energy use of chemical N (nitrogen) fertiliser were assessed given its direct link with the MINAS case. The efficiency of indirect energy use for N fertiliser was re-calculated per unit yield measured in physical units (kg) for the most common crops grown in the Dutch Southwestern Clay Region (sugar beet, winter wheat and ware potato).

The efficiency scores of the participants in the workshop were calculated simultaneously with the scores of the other farmers in the Dutch Farm Accountancy Data Network (FADN) data set. In this way, the calculated efficiencies of the participants were based on the relative distance to the same frontier used for the efficiency calculation of the other farms.

3.5 Data

The analysis was carried out for arable farms located in the Southwestern Clay Area of the Netherlands. In this study, data describing the production activities of specialised arable farmers were from the FADN data set. The analysis was done for the year 1997, the most recent relatively normal weather year. Summary statistics of the full group of 57 farmers are given in Table 2.1. Nine farmers from this group participated in the workshop. Their characteristics are shown separately in Table 2.1. The table indicates some differences between the workshop participants and the total group. On average, the workshop participants were 10 years younger than the full group of arable farmers and their farms were larger. Above all their Gross Margins (DFL/ha) were significantly higher. An explanation for the latter can be found in the higher percentage of vegetables in the cropping plan of the workshop farms, which are characterised by higher gross margins. Furthermore, the workshop participants applied relatively high doses of chemical nitrogen and their application of organic nitrogen was, on average, not lower, when compared with the total group. In line with these observations, the workshop participants obtain higher yields for winter wheat and ware potato but lower yields for sugar beet (the sugar concentration in beets is negatively affected by high N dosages). In conclusion, the workshop participants can be characterised as relatively

young farmers with larger farms, a significantly better economic performance and high levels of nitrogen application.

Table 2.1. Summary statistics of the total data set of farmers in the Southwestern Clay Area and the participants in the workshop

Variables	Average		Standard deviation	
	Total N=57	Workshop N=9	Total N=57	Workshop N=9
Gross Margin (DFL/ha)	4820	6350	2153	4166
Indirect energy use (GJ/farm)	978	1066	678	483
Ind. energy fertiliser (GJ/farm)	544	585	384	289
Age farmer (years)	51	43	12	9
Farm size (ha)	63.6	69.2	42.1	37.8
Potato				
Potato area (ha)	13.3	16.0	10.0	7.9
Yield (ton/ha)	52.4	51.1	8.0	7.9
Gross margin (DFL/ha)	5943	6643	2392	1623
Ind. energy N fertiliser (GJ/ha)	15.3	14.4	4.3	3.1
Sugar beet				
Sugar beet area (ha)	10.4	11.1	7.8	8.0
Yield (ton/ha)	63.9	63.7	7.7	5.8
Gross margin (DFL/ha)	6721	6442	1097	1098
Ind. energy N fertiliser (GJ/ha)	7.2	7.9	2.5	3.1
Winter wheat				
Winter wheat area (ha)	16.5	17.0	13.0	12.5
Yield (ton/ha)	7.4	7.5	0.9	0.9
Gross margin (DFL/ha)	2141	2274	360	376
Ind. energy N fertiliser (GJ/ha)	9.6	9.7	1.9	2.2

4. RESULTS

4.1 Workshop

By far the most important goal of the farmers who attended the workshop was ‘a reasonable income’. ‘Labour satisfaction’, ‘farm continuation’, ‘being self-employed’ and ’maximum profit’ had reasonable scores.

Concerning the external analysis, it was found that six of the farmers had attended one or more information meetings on MINAS. The remaining three already participated in MINAS voluntarily. The answers to the knowledge questions indicate that the farmers were not very familiar with the accounting rules. Only three indicated that the yield level is irrelevant, which is correct. Only 50% knew the correct answer that for MINAS the crop species is irrelevant. More than two thirds of the farmers

gave the right answer (yes) to the last question, namely whether it is important to register possible positive results on the nutrient balance sheet.

With regard to the internal analysis, four of the farmers mentioned 'shortage of nitrogen' as the major obstacle of the introduction of MINAS. Five mentioned 'the low organic matter content in the soil' as an obstacle. In general, the latter group consisted of the farmers who did not mention 'nitrogen shortage' as a problem. Analysis of their current fertilisation tactic showed that three farmers indicated a wrong obstacle; four farmers indicated a potential obstacle which however was not applicable given their yield levels, and only two farmers indicated their real obstacles.

When the optimal tactic resulting from the interactive simulation was compared with the tactic indicated before the simulation session, significant differences were found. The farmers' expectations about the use of nitrogen fertiliser did not agree with the results of the simulation. Most workshop attendees expected to have to reduce the amount of nitrogen applied in order to avoid being taxed for nitrogen surpluses, yet simulation showed that this would not be necessary. Seven farmers expected that they would have to reduce the amount of manure they spread on the fields, but the simulation results agreed with only two of them. Almost all participants expected MINAS to depress yields, but the simulation model showed that such an effect could easily be avoided. In general, the nutrient surplus per hectare farmers expected was much higher than the surplus calculated by the simulation model. In conclusion, the farmers were much too negative about the effects of MINAS and this was reflected in too stringent modifications to their fertilisation management. Comparison of the original fertilisation plans with those of the simulation session resulted in quality scores for synthesis of 2, 1, 0.5 and 0 points for 1, 2, 2 and 4 farmers, respectively.

4.2 Technical efficiency

The TE values of farmers with regard to indirect energy use are presented in Table 2.2. The results show that the average TE values, measured in units energy per unit revenue, and measured per unit physical output were similar for the two groups except for sugar beet where the participants score lower. Furthermore, the results show that there is considerable scope for improvement of the efficiency: the average TE values range from 61 % at farm level to 33% in sugar beet. The scores between the individual crops differ significantly.

Table 2.3 shows a significant positive rank correlation between TE for indirect energy of fertiliser use at the farm level with TE for winter wheat.

Table 2.2. Technical efficiency (%) of indirect energy use of the full group and of the participants in the workshop measured in J/DFL and J/kg on farm level and crop level respectively

Technical efficiency	Full group N=57	Participants N=9
Indirect energy fertiliser	61	63
Indirect energy N-fertiliser		
ware potato	44	45
sugar beet	33	27
winter wheat	51	51

Table 2.3. The rank correlation between technical efficiency (%) at farm level and gross margins (DFL/ha) and the technical efficiency N fertiliser of winter wheat, ware potato and sugar beet (measured in J/kg)

Rank correlation between …	and TE N fertiliser of		
	winter wheat	ware potato	sugar beet
TE farm level			
Chemical fertiliser	0.21[a]	0.04	-0.16
Gross Margin			
winter wheat	0.40[b]		
ware potato		0.23	
sugar beet			0. 28[a]

[a] Correlation is significant at the 0.05 level (2-tailed) .
[b] Correlation is significant at the 0.01 level (2-tailed).

No correlation was found with ware potato, while a negative rank correlation was found with TE for sugar beet. Interesting is whether a technically efficient production practice coincides with a higher income. Since there are differences in total cropping plan this is analysed on crop level by looking at the rank correlation between TE and the gross margin of the specific crop. Table 2.3 shows significant positive rank correlations except the rank correlation with ware potato which was not significant. These positive correlations imply that for this sample of farmers a more technically efficient production practice coincides with a higher income indeed.

4.3 Strategic management related to technical efficiency

The rank correlations between the elements of strategic management and TE are presented in Table 2.4. None of these correlations were significant at the critical 5% level. The results show that for the TE of potato and

sugar beet negative correlations were found with the elements of the strategic management concept except for the correlation between the external analysis and the TE of sugar beet, and the economic mission and the TE of ware potato. The correlations between TE of winter wheat on the one hand and the scores for the economic mission, the external analysis and the synthesis respectively on the other were positive, as were the correlations between TE at farm level and the economic mission, the internal analysis and synthesis respectively. A negative rank correlation was found for TE at farm level and the external analysis.

Table 2.4. The correlation between the technical efficiency N-fertiliser of winterwheat, ware potato and sugar beet (measured in J/kg) and the technical efficiency chemical fertiliser at farm level (measured in J/DFL) and the elements of strategic management

	TE wheat	TE potato	TE beet	TE fertiliser
economic mission	0.42	0.08	-0.12	0.49
external analysis	0.18	-0.22	0.05	-0.50
internal analysis	0.01	-0.12	-0.39	0.31
synthesis	0.36	-0.01	-0.24	0.36

5. DISCUSSION

The calculated TE scores for the individual crops are significantly different (Table 2.2). The calculated TE for sugar beet is particularly low compared with the TE for potato and wheat. A possible reason is the negative effect of high nitrogen doses on sugar yield, which does not apply to potato and winter wheat. The relatively low TE value for ware potato might be due to the differences in varieties planted. The most common varieties are Agria and Bintje. Agria needs less nitrogen and gives higher yields. Not all farmers can grow this variety, however, as the seed potatoes of Agria are much more expensive and supply is limited.

A negative rank correlation was found between TE of sugar beet and TE at farm level (Table 2.3). This suggests that when farmers apply relatively low nitrogen doses in sugar beet, they give relatively higher doses in other crops. Application of relative low nitrogen doses in sugar beet suggests good cropping practice, as the yield level of sugar is negatively correlated with high doses of nitrogen. This reasoning implies that an analysis of energy efficiency should not be carried out solely per individual crop but in association with the results at farm level and/or for the other crops. Due to differences in the cropping plans of the individual farms, however, this would complicate the analysis.

The economic character of the mission was correlated positively with the TE of winter wheat and TE at farm level, and had a relatively

weak negative correlation with TE of sugar beet. This suggests that farmers with a strong economic orientation give relatively low nitrogen doses only in winter wheat which has a low gross margin while in potato and sugar beet they might give relatively high doses in order to prevent yields being depressed by nitrogen shortage.

The external analysis correlated positively TE of winter wheat, while there was a negative correlation with TE of potato and TE at farm level. This means that knowledge of MINAS is negatively correlated with a more efficient use of indirect energy. As an inefficient use of indirect energy suggests a relative high fertiliser input, inefficient farms might be more affected by the introduction of MINAS and therefore they were more interested in MINAS.

The measurement of the elements of strategic management showed that the external and internal knowledge of the workshop participants was poor, as was their capacity to synthesise an optimal fertiliser strategy. The measurement of the efficiency showed that there was considerable scope for improvement and that this might be interesting from economic point of view. Furthermore, the positive correlation between the technical efficiency at farm level and the internal knowledge and the synthesis indicates that improvement of these management aspects could improve the efficiency. Overall, these results imply that a considerable improvement of indirect energy use efficiency could be realised by assisting farmers to analyse their own farm data and by the assessing an appropriate fertilisation strategy. Communication on the positive correlation between the technical efficiency and realised gross margin should improve farmers' interest on this subject.

6. CONCLUSIONS

The main objective of this chapter was to explain differences in the technical efficiency of indirect energy use of Dutch arable farmers through differences in management in order to obtain keys for the reduction of indirect energy use. The results of the analysis of management aspects showed that: the farmers in the sample had a poor knowledge of relevant agri-environmental policy for crop farming and of their own farm data and that it was difficult to synthesise the relevant information into an optimal fertilisation strategy.

The results of the DEA analysis showed that: there was a large variation in TE between farms and crops. The average scores varied between 33% and 61 %, indicating that for some of the farms and/or crops there is scope for improving TE. Furthermore, a positive correlation was

found between TE of the individual crops and the gross margins, indicating that a more technically efficient production practice coincides with a higher income.

From the comparison of the various TE scores of the nine farmers in the workshop with their scores for internal/external analysis, synthesis and for the degree of their economic mission, the following main conclusions were drawn: the economic mission, the internal analysis and the economic mission were positively correlated with the efficiency of indirect energy use at farm level, while the external analysis was negatively correlated.

Overall it can be concluded that there is scope for a considerable reduction of indirect energy use by giving farmers management support in analysing their own farm data and formulating an optimal fertilisation strategy.

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NOTES

[1] 1 DFL ≈ 0.5 $US ≈ 0.5 EURO.

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Chapter 3

ENERGY INVESTIGATIONS OF DIFFERENT INTENSIVE RAPE SEED ROTATIONS – A GERMAN CASE STUDY

Johannes Moerschner and Wolfgang Lücke

1. INTRODUCTION

Energy use, energy intensity and energy productivity can be applied as a kind of standard for energy related comparisons of products, production processes, farms or farming systems. In this contribution the impacts of different intensive rape seed rotations on these criteria are compared based on data out of nine years of investigation at two sites nearby Göttingen in Lower Saxony, Germany. The advantages of the investigated systems depend on the used energy criteria and on the functional units chosen. Potential options for changes in cropping strategies with regard to energy reduction were identified to be strongly dependend on the specific local conditions.

Investigations on energy aspects can be applied to illustrate differences in environmental characteristics of agricultural production systems. Energy use is generally correlated with greenhouse gas emissions and with depletion of natural resources. In order to reduce both, emissions as well as depletion of natural resources, potentials for energy saving in farming activities have to be identified. This may lead to site specific optimised energy intensities in production. Furthermore, potentials for a substitution of fossil fuels used on farm by renewable ones may be derived in a second step from an energy analysis as presented here, *e.g.* application of biofuels instead of diesel fuel.

2. MATERIALS AND METHODS

The energetical investigations are based on cropping data of the years 1989-1998 from the large scale INTEX-project at the University of Göttingen. In two project periods (1989-94 and 1994-98 resp.), four and

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three different cropping systems respectively were grown simultaneously on two different locations nearby Göttingen. *Reinshof* with its more favourable arable conditions and its high yield potential can be considered as a premium location. In contrast to this, *Marienstein* is a strongly varying location with heavy soils. Situated on the slope of the river Leine, this site is rather typical for the hilly regions of Lower Saxony. Each plot had a size of 1.3 ha to 4.1 ha. Details on further findings of other researchers dealing with economical and ecological aspects of the INTEX-project are found in Gerowitt and Wildenhayn (1997) and Steinmann and Gerowitt (2000).

The presented results below are focussed on the conventional reference systems called 'Good farming practice' with oil seed rape, winter wheat and winter sown barley as typical regional rotation compared to three different integrated farming systems (Table 3.1).

Table 3.1. The investigated cropping systems of INTEX

Farming system	Abbreviation	Years investigated
'Good farming practice'	Conv I+II	1989-1998
'Integrated'	Int	1989-1994
'Integrated flexible'	Int-a	1994-1998
'Integrated without plough'	Int-b	1994-1998

The integrated rotations were adapted according to their intensity of soil cultivation, fertilisation and pesticide use. Furthermore they were extended by one additional crop (field beans, grown after winter wheat until 1994; since 1994 one year of annual set aside at the end of the crop rotation instead) and since 1994 winter sown barley was replaced by oats. Due to the changes, since 1994 oil seed rape in the integrated farming systems was followed by oats, winter wheat and finally by an annual set aside as last year in the rotations.

In the calculations primary energy input (PE) for diesel fuel, motor oil, electricity, seeds, mechanisation, chemical fertilisers (N, P, K, Ca, S) and pesticides (considered as kg active substances applied per ha) was taken into account. The so-called 'cumulated energy requirements' include the energy use during the whole life cycle. Energy demand for production, use and disposal of each product is assumed to consist of the supply of the end energy used during the life cycle and all transportation processes involved.

Diesel fuel and motor oil use on farm were not measured, but calculated with a model, based on Borken *et al.* (1999). The applied amount of P and K fertiliser was calculated with mean figures for the nutrient export by kernel yield [kg t yield^{-1}], the use of CaO was assumed to be 300 kg (ha a)$^{-1}$ according to information of the regional extension

service. Drying of yield with heated air was excluded by system definition. As a simplification for modelling the supply of end energy is considered to be the same for all means of production, *e.g.* electricity is assumed to be provided always in the same way, regardless whether it was actually used for farm activities or for other purposes in the preceding process chains. The energy coefficients used for the energy input calculation are listed in Table 3.2.

Table 3.2. Energy coefficients used for energy accounting (own calculations, based on Gaillard et al. 1997, Kaltschmitt and Reinhardt 1997, Patyk and Reinhardt 1997)

Supplies		**Primary Energy coefficients**
Direct Energy	- Diesel fuel, Motor oil (2 % of fuel)	47.82 MJ/kg
	- Electricity	11.39 MJ/kWh
Seeds (energy for providing the seeds only)	- Field beans	3.55 MJ/kg
	- Grass, Clover and other fine seeds	12.21 MJ/kg
	- Oats	3.28 MJ/kg
	- Oil seed rape	8.43 MJ/kg
	- Sunflowers	3.55 MJ/kg
	- Winter sown barley	3.45 MJ/kg
	- Winter wheat	3.02 MJ/kg
Mineral fertilisers[a]		
Nitrogen	- Urea	59.07 MJ/kg N
	- Urea ammonium nitrate (UAN, liqu.)	52.33 MJ/kg N
	- Calcium ammonium nitrate (CAN)	47.18 MJ/kg N
	- Ammonium sulphate (AS)	17.41 MJ/kg N
Phosphate	- Triple-Superphosphate (TSP)	43.83 MJ/kg P
Potash	- MOP, 40 % K_2O	12.99 MJ/kg K
Limestone	- Calcium carbonate	2.41 MJ/kg Ca
Sulfur	- Ammonium sulphate (AS)	17.41 MJ/kg S
Pesticides	- Active substance	274.46 MJ/kg AS
Farm machinery	- Tractors	122.45 MJ/kg
	- Self propelled harvesters	112.88 MJ/kg
	- Cultivation machinery	109.75 MJ/kg
	- Other machinery and trailers	101.25 MJ/kg

[a] Conversion factors element/nutrient: $P/P_2O_5 = 0.428$; $K/K_2O = 0.826$; $Ca/CaO = 0.714$.

Net energy yield was calculated with the figures in Table 3.3. The gross energy content (GE) of all seeds was subtracted from total energy yield before further calculation, because it has to be considered as a regenerative energy input from a previous time period. The energy

coefficients for seeds as shown in Table 3.2 reflect only the energy necessary for their supply; energy content is given by the figures in Table 3.3.

Table 3.3. Gross energy content of arable products (own calculations based on Universität Hohenheim 1997); reference: 1 kg at standard moisture content [a]

Arable products		**Gross Energy** (GE)
Seeds and kernel yield identical	- Field beans	16.42 MJ/kg
	- Oats	16.30 MJ/kg
	- Oil seed rape	25.72 MJ/kg
	- Winter sown barley	15.79 MJ/kg
	- Winter wheat	15.79 MJ/kg
Other seeds	- Grass, clover and other fine seeds	16.40 MJ/kg
	- Sunflowers	25.12 MJ/kg

[a] Oil seed rape: 91 % dry matter content (DM); fine seeds: 100 % DM; Others: 85 % DM

3. RESULTS

System comparisons of energy input as well as of energy intensity and energy productivity for the farming systems were carried out on different levels. Due to differences in the length of rotations (three and four years respectively), the comparison of the farming systems refers to average values for a mean year of each crop rotation. The reliability of the results at this level is investigated afterwards by comparing mean values of all crops between years and by comparing different cultivated crops.

3.1 Energy input

Though considerable relative reductions of the energy input are achievable in some input groups of the integrated systems (Table 3.4), the absolute energy savings were most important in the group 'N-fertiliser', followed by fuel and pesticide use. The energy input for machinery was higher in the integrated systems because of less optimal conditions of depreciation compared to the conventional systems. The last result depends on the applied allocation rules (Table 3.4). Other energy inputs depend directly on the amount of yield (electricity use and basic fertilisation). Therefore, they were only indirectly influenced by changes in the farming systems.

Table 3.4. Energy use profiles [MJ (ha a)$^{-1}$] of the 'Conventional' farming systems and differences in energy input of the integrated systems compared to 'Conventional', mean years of rotations, two different locations

	Groups of supplies							
	Fuel, motor oil	Elec-tricity	Machi-nery	Seeds	Basic fertiliser	N-fertiliser	Pesti-cides	Total
Location Reinshof								
Harvest 1990-94								
Conv I	*2991*	*353*	*2712*	*408*	*2399*	*7684*	*895*	*17442*
Int	-489	-77	188	184	-281	-3320	-716	-4511
Harvest 1995-98								
Conv II	*2925*	*326*	*2734*	*400*	*2551*	*7017*	*521*	*16474*
Conv II[a]	-66	-27	22	-8	152	-668	-373	-968
Int-a[b]	-565	-98	221	-118	-599	-3641	-373	-5174
Int-a[c]	-158	-21	774	-32	-121	-2516	-323	-2398
Int-b[b]	-1390	-107	31	-109	-630	-3659	-151	-6015
Int-b[c]	-1082	-34	649	-20	-162	-2540	-27	-3217
Location Marienstein								
Harvest 1990-94								
Conv I	*2711*	*307*	*2685*	*410*	*2203*	*9094*	*789*	*18201*
Int	-416	-87	91	178	-450	-3350	-441	-4475
Harvest 1995-98								
Conv II	*2713*	*306*	*2630*	*415*	*2442*	*8373*	*628*	*17506*
Conv II[a]	1	-1	-55	5	238	-721	-162	-695
Int-a[b]	-371	-104	288	-127	-679	-4142	-433	-5567
Int-a[c]	45	-36	816	-46	-263	-2732	-368	-2584
Int-b[b]	-1192	-118	184	-121	-728	-3971	-178	-6123
Int-b[c]	-898	-56	779	-38	-329	-2504	-28	-3072

Conv = 'Conventional'; Int = 'Integrated'; Int-a = 'Integrated flexible'; Int-b = 'Integrated without plough'

[a] Energy input difference in comparison to Conv I.

[b] Annual set aside included in rotation (n = 4).

[c] Only productive crops, annual set aside not taken in account (n = 3).

The total area related energy savings in the 'Integrated' systems of the first project period [MJ (ha a)$^{-1}$] amounted to 25.9 % and 24.6 % (*Reinshof* and *Marienstein* resp.) compared to the references (Table 3.4). In the second project period the saved area related energy in 'Integrated flexible' amounted to 31.4 % and 31.8 % (*Reinshof* and *Marienstein* resp.). 'Integrated without plough' was even slightly better (36.5 % and 35.0 % resp.). If annual set aside is excluded, the advantages in energy use for the integrated systems in the second project period are much smaller (Table 3.4, lower lines Int-a, Int-b). Furthermore the energy input in the reference systems of the second project period became slightly lower (-5.6 %

Reinshof, -3.8 % *Marienstein* resp.; Table 3.4). That was affected mainly by a lower amount and changes in the applied types of N-fertilisers (introduction of ammonia sulphate) and by lower mean yields. The ranking of the systems according to the area related energy use for mean years on rotation level is found to be very stable over all investigated years (Figure 3.1). 'Integrated flexible' and 'Integrated without plough' were similar; though in most years the latter had the lowest energy input on both sites.

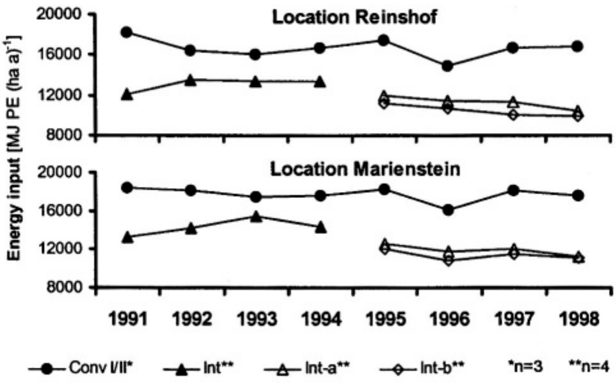

Figure 3.1. Energy use [MJ (ha a)$^{-1}$] in the conventional and the integrated systems, each year mean values of all crops in the crop rotations, two different locations, annual set aside included (Conv = 'Conventional'; Int = 'Integrated'; Int-a = 'Integrated flexible'; Int-b = 'Integrated without plough'; n = number of crops)

Total area related energy input showed considerable differences between locations and crops. As a tendency, it was higher at location *Marienstein* (Table 3.5). Most crops had a higher demand of energy in the reference systems than in the integrated systems compared. Table 3.5 shows a lower energy use per ha for 'Integrated without plough' than for 'Integrated flexible' for the majority of crops. Oil seed rape, winter wheat and winter barley can be labelled as energy intensive crops, whereas oats and field beans often need only little more than half of the energy input of these crops (Table 3.5).

3.2 Energy intensity

Energy intensity of single crops (Table 3.6) was expressed as [MJ t dry matter^{-1}]. For investigations of energy intensity of whole crop rotations, energy had to be aggregated as input per grain unit [MJ GU^{-1}]. GU is a German unit defined before the second world war for standardised evaluation of different agricultural products, based on starch units, crude

protein contents and on their net energy (cereals: 10 GU t^{-1}; oil seed rape: 20 GU t^{-1}; field beans: 12 GU t^{-1}). By this way GU also takes into account differences in nutritional values. To get the same relation in energy intensity for single crops (MJ GU^{-1}), the figures in Table 3.6 have to be divided by the factors indicated above and by the corresponding standard dry matter contents (see Table 3.3). All crop yield were corrected beforehand by the input of seeds for the main crops.

Table 3.5. Mean total energy use [MJ (ha a)$^{-1}$] for all cultivated crops in the 'Conventional' and integrated systems, two different locations

	Crops					
	Rape seed	Winter wheat	Winter barley	Oats	Field beans	Ann. set aside
Location Reinshof						
Harvest 1990-94						
Conv I	17147	18651	16528	-	-	-
Int	15564	14534	12846	-	8780	-
Harvest 1995-98						
Conv II	15245	17552	16624	-	-	-
Int-a	15951	17467	-	8809	-	2973
Int-b	15398	16234	-	8138	-	2063
Location Marienstein						
Harvest 1990-94						
Conv I	17313	19487	17802	-	-	-
Int	16315	16023	15063	-	7501	-
Harvest 1995-98						
Conv II	16211	19133	17174	-	-	-
Int-a	15549	18339	-	10880	-	2989
Int-b	15873	17508	-	9921	-	2230

Conv = 'Conventional'; Int = 'Integrated'; Int-a = 'Integrated flexible'; Int-b = 'Integrated without plough'.

In energy intensity, only some tendencies could be identified for the ranking of systems, because each location had its own profile. Under good farming conditions (*Reinshof*) the integrated systems were often in the same range of specific energy use [MJ GU^{-1}] as the reference systems, or below them. Under less favourable farming conditions (*Marienstein*) the ranking changed annually, between the integrated systems as well as between 'Conventional' and 'Integrated' in general (Figure 3.2). It is obvious that at this site the yields of the farming systems were more sensible to the annual natural conditions than at *Reinshof*. However, in the first cropping period at *Marienstein* (1990-94) the specific energy use in the system 'Integrated' seems to be generally higher than 'Conventional' (Figure 3.2).

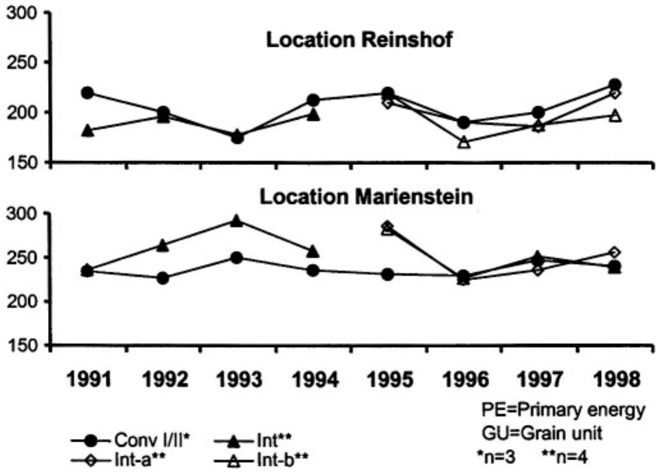

Figure 3.2. Energy intensity [MJ GU^{-1}] in the conventional and the integrated systems, each year mean values of all crops in the crop rotations, two different locations, annual set aside included (Conv = 'Conventional'; Int = 'Integrated'; Int-a = 'Integrated flexible'; Int-b = 'Integrated without plough'; n = number of crops)

Table 3.6. Mean energy intensity of all crops [MJ (t dry matter)$^{-1}$] and of crop rotations [MJ GU^{-1}], conventional and integrated systems, two different locations

		Crops					Rotations
	n	Rape seed	Winter wheat	Winter barley	Oats	Field beans	Mean values
Location Reinshof							
Harvest 1990-94							
Conv I	3	4627	1916	1992	-	-	206
Int	4	4101	1872	1826	-	2159	190
Harvest 1995-98							
Conv II	3	4347	1967	2173	-	-	210
Int-a	4	4211	2167	-	1273	-	200[a]
Int-b	4	4111	2012	-	1313	-	192[a]
Location Marienstein							
Harvest 1990-94							
Conv I	3	4426	2356	2657	-	-	240
Int	4	5796	2441	2378	-	3176	257
Harvest 1995-98							
Conv II	3	4907	2209	2509	-	-	237
Int-a	4	6034	2301	-	1800	-	249[a]
Int-b	4	5476	2312	-	2021	-	249[a]

Conv = 'Conventional'; Int = 'Integrated'; Int-a = 'Integrated flexible'; Int-b = 'Integrated without plough'; n = number of crops in rotation

[a] Annual set aside included in rotation (n = 4).

In contrast to the area related results, energy intensity for winter wheat in the second period was lower in the conventional systems, due to the higher yields. However, it remained higher for oil seed rape in this system at location *Reinshof*, where the mean yield was sometimes higher in the integrated systems (Table 3.6). Furthermore, oil seed rape at *Reinshof* always needed more than twice the energy input for one tonne of yield than the most intensive cereals winter wheat and it was even higher in *Marienstein.* The extensive crop oats was identified as the most energy efficient one at both locations, because cultivated after oil seed rape had a very low demand for N-fertilisation (Table 3.6). However, for all crops, the specific energy input in *Marienstein* was generally higher than in *Reinshof,* due to the lower yields and to a higher specific intensity of cropping in most crops at this site.

3.3 Energy productivity

As Figure 3.3 shows, energy productivity (=net energy yield; [GJ $(ha\ a)^{-1}$]) was higher at location *Reinshof* than at the less favourable location *Marienstein*; for a mean year of rotation almost 20 GJ $(ha\ a)^{-1}$.

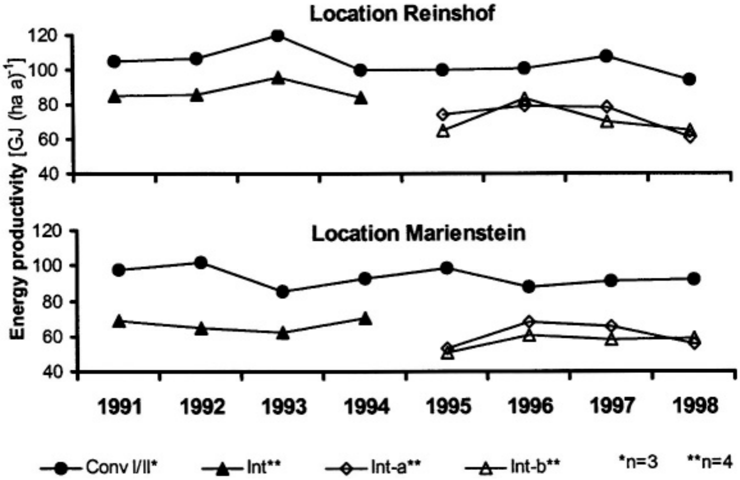

Figure 3.3. Energy productivity [GJ $(ha\ a)^{-1}$] in the conventional and the integrated systems, each year mean values of all crops in the crop rotations, two different locations, annual set aside included (Conv = 'Conventional'; Int = 'Integrated'; Int-a = 'Integrated flexible'; Int-b = 'Integrated without plough'; n = number of crops)

Due to their high yields, the reference systems at *Reinshof* were capable of producing up to approximately 120 GJ $(ha\ a)^{-1}$ of mean net

energy yield, whereas the integrated systems always had net energy outputs which were at minimum 20 GJ $(ha\ a)^{-1}$ lower than ‘Conventional’, provided annual set aside was included (Figure 3.3 and Table 3.7). Comparable values for the systems Int-a and Int-b taking in account only the productive crops can be calculated from the givings in Table 3.5 and Table 3.7. They show much smaller deviations from the reference systems.

Table 3.7. Mean net energy yield [GJ GE (ha a)-1] of all crops and of crop rotations, conventional and integrated systems, two different locations

	n	Crops: Rape seed	Winter wheat	Winter barley	Oats	Field beans	Rotations: Mean values
Location Reinshof							
Harvest 1990-94							
Conv I	3	78.15	135.03	114.45	-	-	109.21
Int	4	82.05	107.94	98.22	-	57.20	86.35
Harvest 1995-98							
Conv II	3	74.94	123.33	104.16	-	-	100.81
Int-a	4	81.46	109.81	-	103.98	-	73.06[a]
Int-b	4	80.93	111.15	-	92.95	-	70.73[a]
Location Marienstein							
Harvest 1990-94							
Conv I	3	83.29	111.11	87.95	-	-	94.12
Int	4	56.08	87.51	84.92	-	30.48	64.75
Harvest 1995-98							
Conv II	3	68.75	117.61	90.89	-	-	92.42
Int-a	4	50.72	107.46	-	87.64	-	60.69[a]
Int-b	4	58.67	102.03	-	70.10	-	57.13[a]

Conv = ‘Conventional’; Int = ‘Integrated’; Int-a = ‘Integrated flexible’; Int-b = ‘Integrated without plough’; n = number of crops in rotation
[a] Annual set aside included in rotation (n = 4).

Comparing single crops between the cropping systems, the net energy yield of the integrated oil seed rape at *Reinshof* was almost the same (Int) or higher than in the reference system (Int-a, Int-b resp.). In *Marienstein*, the reference system remained the most favourable one in both project periods (Table 3.7). The cereals in the integrated systems were not competitive with their conventional counterparts, except oats which – for comparison - must be seen as the integrated substitute for winter barley in the reference system of the second project period. Consequentely, the mean annual net energy yield in most cases remained below the reference rotation, even if the annual set aside of the second project period was excluded in the calculation of the integrated systems. Between the systems ‘Integrated flexible’ and ‘Integrated without plough’ only some slight

preferences for the first are found (*Marienstein*), though at both locations no clear ranking for all years was identified (Figure 3.3).

4. SOME POINTS OF DISCUSSION

4.1 Methodical approach of energy accounting

Energy calculations always include some degree of uncertainty. Absolute figures can be substancially influenced by

- the energy coefficients used
- the algorithms applied to estimate quantities for substance flows not measured, *e.g.* the specific fuel use of each work
- details of the system boundaries, such as substance flows or processes which were excluded by definition.

Therefore, a framework for comparisons with other results must be carefully prepared. The ranking of the farming systems in the investigated energy criteria is in general not influenced by changes in the underlaying energy coefficients. The used cropping data were calculated with five alternative energy data sets from other studies without major differences in the general system ranking (Moerschner 2000).

When the gross energy incorporated in the seeds is subtracted from the total energy yield, as suggested in this study, the related substance and energy flows don't have the same physical basis. This causes some problems in terms of LCA-methodology. This way of calculation was chosen for better comparison with other energy studies on the input side. When data for LCA-applications should be provided, it may be a better solution to include the inherent energy of seeds into the energy coefficients used and indicate the share of incorporated solar energy and process energy. However, in the presented energy analysis the relations between the systems are not sensitive to such a change.

Machinery is often excluded in energy use studies of farming systems. In economic interpretations, capital goods are counted as fixed costs that are not included in gross margins. In this case study machinery was included because changes in cultivation intensity also cause impacts on the annual intensity in farm machinery use on a given area. As consequence, a reduced cultivation intensity should result in a reduction of applied farm machinery as well, because otherwise, their depreciation becomes an important energetical load within total energy budgets (Moerschner 2000).

4.2 Background of results and critical view on the way of their presentation

The reduction in energy use for N-fertilisation in the rotations of the integrated systems had the greatest impact on the results of the first project period. This reduction was first of all due to the low input crop field beans. Furthermore a site specific flexible reduction in overall cropping intensity can be stated (Table 3.5). In the second project period the introduction of oats into the integrated rotations was most successful in reducing the total energy input in comparison to 'Conventional'. This crop conserved great parts of the nitrogen left in the soil by the preceding crop oil seed rape after harvest with the positive consequence, that the highly energy consuming N-fertilisation for oats was reduced nearly until zero. Furthermore only very few pesticides were spread in this crop.

Annual set aside in the fourth year of the crop rotations of the integrated systems caused further important reductions of the mean area related energy input [MJ $(ha\ a)^{-1}$]. They were accompanied by a considerable reduction in mean energy intensity [MJ GU^{-1}] and - as a negative aspect – by a reduction in mean energy productivity [GJ $(ha\ a)^{-1}$] of the integrated rotations.

The decision to include the annual set aside into the integrated rotations was a result of a policy choice. Annual set aside was not essential for running the integrated farming systems. However, it certainly had positive ecological effects on the other crops, too. Therefore, it appeared to be one comprehensive way of analysis to generally include the annual set aside into the comparisons on rotation level.

Grain units (GU) were used for aggregated considerations of energy intensity. By this means only, whole rotations could be analysed in their energy intensity. The impacts of the integrated systems on gross margins have been the subject of other investigations and thus were excluded from the argumentation in this chapter (see materials and methods).

5. CONCLUSIONS

Reductions in production intensity can be better established under good farming conditions as represented by the location *Reinshof*. The losses in productivity observed at *Marienstein* were higher. The observed negative impact of annual set aside (Int-a, Int-b resp.) in this context might be reduced by replacing set aside by a productive crop. The design of the new

rotation seems to be a key issue among all factors determining energy saving through changes in the farming system.

The energy analysis has shown, that a site specific flexible reduction in farming intensity, depending on local natural conditions can open interesting potentials for saving (fossil) energy resources and at same time provides additional ecological advantages.

The interpretation of diesel fuel energy input finally demonstrates - besides possible savings when using reduced soil cultivation practices - the potentials for the introduction of more sustainable energy sources like biodiesel.

ACKNOWLEDGEMENTS

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Chapter 4

MODELLING ENERGY SAVING TECHNOLOGY CHOICES IN DUTCH GLASSHOUSE HORTICULTURE

Kyosti Pietola and Alfons Oude Lansink

1. INTRODUCTION

This chapter applies Simulated Maximum Likelihood (SML) for estimation of a multinomial Probit model of technology choices on Dutch glasshouse firms. The model allows for time constant firm specific effects and serial correlation of errors and is estimated on panel data over the period 1991-1995.

The Dutch glasshouse industry is traditionally an important user of energy, accounting for 4% of total CO_2 emissions in the Netherlands. In order to reduce the use of energy and related CO_2 emissions, the Dutch government and the glasshouse industry made a covenant aiming at improving the energy efficiency by 65% in 2010 compared to the level in 1980 (Stuurgroep Landbouw en Milieu 2000). Firm operators also have an incentive for reducing energy use, since energy is a major determinant of profitability on glasshouse firms, accounting for approximately 33% of variable costs on glasshouse firms.

Firm operators in the glasshouse industry have several options for saving energy in the production process. One set of options is related to the structure of glasshouses and includes double glazing and thermal screens. Another set of options is related to heat producing installations such as traditional installations, co-generators[1], heat deliveries by electricity plants and heat storage (van der Velden 1996). This chapter aims at explaining the relative importance of different factors underlying the choice of heat producing installations on Dutch glasshouse firms.

Technology choices often represent long term commitments in which timing and future returns play important roles. These choices are, therefore, solutions to dynamic optimisation problems, which can be

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modelled either in structural or reduced form using the optimal stopping framework and dynamic programming (*e.g.* Rust 1987). In this study the model is first derived in structural form and then approximated by a reduced form specification. Next, discrete choices in energy saving technologies are estimated by explicitly allowing for a flexible error structure. Individual, time constant (random) effects and first order serial correlation in the choices are special cases of the general error structure in the model. Controlling for random effects in estimating the firm operators' technology choices is important because the choices may be affected by unobservable factors related to the firm operator (*e.g.* education and managerial ability) and firm (*e.g.* climate). It is also important to control for serial correlation since the technology choices are persistent over time due to the presence of adjustment costs.

The model is estimated using a Monte Carlo simulation technique, known as the GHK simulator, developed in the early 90's by Geweke, Hajivassiliou and McFadden, and Keane (Keane 1993; Hajivassiliou 1993). Hajivassiliou *et al.* (1996) compares a number of probability simulators and finds that the GHK simulator outperforms all other methods by keeping a good balance between accuracy and computational costs. This simulation approach is particularly tractable in simulating probabilities for multiple choices that would otherwise require multidimensional integration and intensive computation. Further, the GHK-method can easily be extended to modelling choice alternatives recursively as sequences of choices such that the choice sequences exhibit both time constant individual effects and flexible time series characteristics. The method is used for analysing factors determining the choice of energy saving technologies by Dutch glass house firms using panel data over the period 1991-1995. The results obtained by the SML method are compared with the results from a standard multinomial logit model.

The chapter proceeds with the presentation of the theoretical and empirical models underlying the choice of an energy saving technology, followed by a description of the data and a discussion of the results.

2. THEORETICAL MODEL

This section elaborates on a framework in which operators of glasshouse firms decide among K possible technologies in each of N (finite) discrete periods of time. Alternative technologies are indicated by a dummy variable $d_k(t)$, with $d_k(t)=1$ if technology k is chosen at time t and $d_k(t)=0$ otherwise. The condition $\sum_{k=1}^{K} d_k(t) = 1$ indicates that alternatives are

mutually exclusive. Also, each technology option is associated with a reward function $R_k(t)$ that is known to the firm operator at time *t,* but that is random from the perspective of periods prior to *t, i.e.* the firm operator does not know the outcome with certainty prior to *t.*

The objective of the firm operator at any time $t=0,..,N$ is to maximise the discounted present value of the rewards, $R_k(t)$. The optimal value function $V(\cdot)$ for the problem then solves:

$$V(S(t),t) = \max_{\{d_k(t)\}_{k\in K}} E\left[\sum_{\tau=t}^{N} \beta^{\tau-t} \sum_{k\in K} R_k(\tau) d_k(\tau) \middle| S(t)\right] \tag{4.1}$$

where $\beta > 0$ is the discount factor, $E(\cdot)$ is the mathematical expectations operator, and $S(t)$ is the predetermined state space at time *t.* The state space consists of all factors, known to the firm operator that affect the current period reward (*e.g.* input and output prices). Maximisation of (4.1) involves choosing the optimal sequence of control variables $(d_k(t))$ over the finite horizon of $t=0,..,N$.

The optimal value function can be rewritten as (Keane and Wolpin 1994):

$$V(S(t),t) = \max_{k\in K}\{V_k(S(t),t)\} \tag{4.2}$$

where $V_k(S(t),t)$ isthe technology *k* specific value function that satisfies the Bellman equation of the form (Bellman 1957):

$$V_k(S(t),t) = R_k(S(t),t) + \beta E\left[V(S(t+1),t+1) \middle| S(t), d_k(t) = 1\right],\ t \le N-1 \tag{4.3}$$

subject to a certain set of transition equations for the current state $S(t)$.

Augmenting V_{kt} by an error term v_{kt}, technology k is chosen and $d_k(t)=1$ if

$$V_{kt} + v_{kt} > V_{jt} + v_{jt},\quad \forall j \neq k \tag{4.4}$$

which implies

$$v_{kt} - v_{jt} > V_{jt} - V_{kt},\quad \forall j \neq k \tag{4.5}$$

Thus the boundaries for the choices are determined by the differences between the technology specific value functions and by the differences of the corresponding errors.

3. EMPIRICAL MODEL

The structural form estimation of (4.2), (4.3) and (4.5) would require a solution for the technology specific value functions by, for example, numerically iterating on the Bellman equations (4.3) conditional on some functional specification for the one period returns $R_k(\theta)$ and trial values for the parameters θ. The parameter values could then be updated estimating the behavioural equations given by (4.5). The structural form estimation is computationally very demanding since it requires numerical simulation of the expected values for the next period's optimal value functions, *i.e.* for expected maximums for the future revenue steams that are stochastic and dependent on the technology choices[2].

A computationally less demanding approach is to normalise the boundaries of the distribution of the errors of the choice equations by the value of one technology and approximate only the differences of the technology specific value functions by a reduced form representation (*e.g.* Dorfman 1996).

In this study the farmer's choices are estimated in reduced form for two reasons. First, given the small number of years in the panel data it would be problematic to accurately simulate the dynamic structure of the technology specific and stochastic returns processes. Large simulation errors would bias the estimates for the expected next period optimal value functions because the optimal value function is highly non-linear function of the simulation errors (Keane and Wolpin 1994).

Second, because the choices are based on the differences of the technology specific returns streams (not on the level of each returns stream) the reduced form is empirically tractable. Approximation errors between the structural optimal stopping model and the reduced form models are found negligible (Provencher 1997)[3]. The results of Pietola and Oude Lansink (2001) also indicate that the structural form simulation does not significantly add information in estimating the conditional choice probabilities. A reduced form specification has also been the standard in the earlier studies on discrete technology choices (*e.g.* Green *et al.* 1996).

The method that is used to estimate the reduced form model is referred to as Simulated Maximum Likelihood (see Arias and Cox (1999) for an introduction). In our application, at time t, firm *i* chooses $d_k^i(t)=1$ if

$$\varepsilon_{kj,t}^i > X_t^i\beta_{kj}, \forall j \neq k \tag{4.6}$$

Where, $\varepsilon_{kj,t}^i = v_{kt}^i - v_{jt}^i$, $X \in S$ is a vector of instruments, and β is a vector of parameters[4]. Similarly, $d_k^i(t)=0$ is chosen if $\varepsilon_{kj,t} < X_t\beta_{kj}$ at

least for one $j \neq k$. For given *k* and *j*, the two boundaries (inequalities) can be stacked in (Keane 1993)

$$(2d_{k,t}^{i} - 1)\varepsilon_{kj,t}^{i} > (1 - 2d_{k,t}^{i})X_{t}^{i}\beta_{kj} \qquad (4.7)$$

Dropping the *kj* subscripts, the sequence of errors $\varepsilon^{i} = \{\varepsilon_{1}^{i}, \varepsilon_{2}^{i}, ..., \varepsilon_{T}^{i}\}'$ can be further stacked over the sample period *t= 1,2...,T,* as $\varepsilon^{i} = A\eta^{i}$, where $\eta^{i} = \{\eta_{1}^{i}, \eta_{2}^{i}, ..., \eta_{T}^{i}\}'$ with $\eta_{t}^{i} \sim N(0,1)$. Matrix *A* is a lower-triangular matrix of the Cholesky decomposition of the covariance matrix Σ such that $\Sigma = AA' = E[\varepsilon^{i}\varepsilon^{i}{}']$. Using these definitions, (4.7) can be written as (Keane 1993):

$$(2d_{t}^{i} - 1)\eta_{t}^{i} > [(1 - 2d_{t}^{i})X_{t}^{i}\beta \; - (2d_{t}^{i} - 1)(A_{t,1}\eta_{1}^{i} + ... + A_{t,t-1}\eta_{t-1}^{i})] / A_{t,t} \qquad (4.8)$$

The GHK simulation technique is to first sequentially draw the errors $\eta_{1}^{i}, \eta_{2}^{i}, ...\eta_{t}^{i}$ from a truncated univariate normal distribution such that they are consistent with the observed choices, *i.e.,* the inequality (4.8) given above holds for each draw. The simulation is started at time *t =1* by drawing η_{1}^{i} (with other $\eta^{i}{}'s$ being zero) for each farm *i* such that the draw is consistent wit the observed choice, *i.e.* the draw satisfies the inequality $(2d_{1}^{i} - 1)\eta_{1}^{i} > (1 - 2d_{1}^{i})X_{1}^{i}\beta$.

If we observe $d_{1}^{i} = 1$ the truncation point consistent with the observed choice is: $\eta_{1}^{i} > -X_{1}^{i}\beta$. Alternatively, if $d_{1}^{i} = 0$ the corresponding truncation point is: $-\eta_{1}^{i} > X_{1}^{i}\beta$.

Next, the truncation point is updated by substituting the first draw, say $\hat{\eta}_{1}^{i}$, for η_{1}^{i} in (4.8). The second error η_{2}^{i} is drawn using the updated truncation point

$$(2d_{2}^{i} - 1)\eta_{2}^{i} > [(1 - 2d_{2}^{i})X_{2}^{i}\beta \; - (2d_{2}^{i} - 1)(A_{1,1}\hat{\eta}_{1}^{i})] / A_{1,1}$$

and substituting this new draw $\hat{\eta}_{2}^{i}$, for η_{2}^{i} in (4.8). This procedure is continued until *t=T.* The sequence of these *T* draws is repeated *S* times for each firm *i.*

The second step is to form the corresponding unbiased simulators for the transition probabilities. Because the computation of these transition probabilities follows a well-established procedure and derivation of these transition probabilities is lengthy, the derivation is omitted here. A detailed

description and discussion on computing the transition probabilities is found in Keane (1993: pp. 550-554).

Our application has three choice alternatives (technologies). Because the choices are mutually exclusive, two binary indicators are sufficient in identifying them. These two binary indicators are defined as follows.

$d_1(t) =$ *1*, if traditional heating with storage is chosen
0, otherwise
$d_2(t) =$ *1*, if co-generator with storage is chosen
0, otherwise.

The third choice of traditional heating without storage is observed if $d_1(t)+d_2(t)=0$.

The log likelihood function, l_t^i, for a single observation has the form

$$
\begin{aligned}
l_t^i(\beta) = {} & d_{t,1}^i(\ln P(d_{t,1}^i = 1 \mid J_{t-1}^i, X_t^i, \hat{\beta}) + \ln P(d_{t,2}^i = 0 \mid J_{t-1}^i, X_t^i, \hat{\beta})) \\
& + d_{t,2}^i(\ln P(d_{t,1}^i = 0 \mid J_{t-1}^i, X_t^i, \hat{\beta}) + \ln P(d_{t,2}^i = 1 \mid J_{t-1}^i, X_t^i, \hat{\beta})) \\
& + (1 - d_{t,1}^i - d_{t,2}^i)(\ln P(d_{t,1}^i = 0 \mid J_{t-1}^i, X_t^i, \hat{\beta}) + \ln P(d_{t,2}^i = 0 \mid J_{t-1}^i, X_t^i, \hat{\beta}))
\end{aligned} \tag{4.9}
$$

where $P(\cdot)$ are the simulated probabilities, conditional on all choices made before time t (J_{t-1}), a set of exogenous instruments (X_t), and trial parameters ($\hat{\beta}$). The set of instruments *X* includes the price of energy, capital stock in structures, capital stock in energy installations, labour, and the size of the operation. These instruments were used in logarithmic forms. Also, dummy variables identifying the vegetable firms and cut flower firms were included in the set of instruments. The GHK simulator was based on 20 draws for the error sequence of each firm (*i.e., S*=20). This number of draws has been found to result only in a negligible simulation bias even when the simulated choice probabilities are small (Börsch-Supan and Hajivassiliou 1993).

The lower-triangular matrices, consisting of the elements that are used in multiplying the simulated error sequences (η's) in the choice equations (for $d_1(t)$ and $d_2(t)$), are denoted by A_1 and A_2. In order to decrease the parameter space and identify the parameters in the model, a set of restrictions was imposed on the elements of A_1 and A_2. All off-diagonal elements were imposed to zero, except for the elements in the first column. Furthermore, the upper most diagonal element in both *A's* was set equal to one implying that $\Sigma_1[1,1] = \Sigma_2[1,1] = 1$ (as in standard Probit

model the variance of the error term is set to one). Since we have data on five time periods, A_1 and A_2 are lower-triangular matrices with size 5*5 and have the following general shape:

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ A_{21} & A_{22} & 0 & 0 & 0 \\ A_{31} & 0 & A_{33} & 0 & 0 \\ A_{41} & 0 & 0 & A_{44} & 0 \\ A_{51} & 0 & 0 & 0 & A_{55} \end{bmatrix}$$

Therefore, 16 unrestricted parameters are left in the model, *i.e.* eight parameters for both A_1 and A_2. The structure of these matrices is general enough to control for firm specific individual effects and serial correlation between the errors.

4. DATA

Data on specialised vegetables firms covering the period 1991-1995 are obtained from a stratified sample of Dutch glasshouse firms keeping accounts on behalf of the LEI accounting system. The panel is balanced such that each firm is in the sample over the full five-year sampling period. The data contain 450 observations on 90 firms.

Three heating technology choices[5] are distinguished, *i.e.* traditional heating, traditional heating with energy storage, and co-generator with energy storage. 345 observations (76%) use the traditional energy heating technology, 39 observations (9%) use traditional heating combined with energy storage in tanks and 66 observations (15%) use a co-generator with energy storage.

Basic firm characteristics are capital invested in structures (buildings, glasshouses, land and paving), capital invested in machinery and installations, labour firm size and firm type. Labour is measured in quality-corrected man years, and includes family as well as hired labour. The quality correction on labour is performed by the Agricultural Economics Research Institute, in order to aggregate labour from able bodied adults with labour from young family members and labour from partly disabled workers. Labour is assumed to be a fixed input in the short term, because family labour represents a large share of total labour. Capital in structures and machinery and installations is measured at constant 1985 prices and is valued in replacement costs. Firm size is measured in

standardised farming units, which is a measure of the income generating capacity of the firm. Firm type is represented by two dummy variables indicating firms specialised in vegetables and cut flowers, respectively (pot plant firms are reference type).

The price ratio of energy and output is calculated from Törnqvist price indices of output and energy with prices obtained from the LEI-DLO/CBS. The price indexes vary over the years but not over the firms, implying prices are exogenous from the perspective of the firm. The price of output consists of prices of vegetables, fruits, pot-plants and flowers. The price of energy consists of prices of gas, oil and electricity, as well as delivery of thermal energy by electricity plants. A description of the data is in Table 4.1.

Table 4.1. Description of data

Variable	Dimension	Mean	Standard Deviation
Dummy standard/storage	1 for standard/storage	0.15	0.35
Dummy co-generator/storage	1 for co-generator/storage	0.08	0.28
Price ratio energy and output	Base year 1985	1.10	0.08
Structures	Guilders*100.000	10.46	8.79
Machinery and Installations	Guilders*10.000	39.71	42.30
Labour	Man years	6.67	3.76
Firm size	Standard Farming Units	746	540
Dummy vegetables	1 if firm is vegetables firm	0.28	0.45
Dummy cut flowers	1 if firm is cut flower firm	0.42	0.49

5. RESULTS

Results of the Simulated Maximum Likelihood (SML) estimation of the multinomial Probit model of energy saving options are found in Table 4.2. The parameter estimates and t-values indicate that five out of eight parameters in both choice equations are significant at the critical 5% level. The parameter estimates are robust to both individual random effects and serial correlation. Table 4.2 also indicates that the intercept of the equation of standard with storage was fixed by the computer program due to poor identification caused by including the dummy variables associated with firm type. Parameter estimates of the matrices $\mathbf{A}_1$ and $\mathbf{A}_2$ are found in Appendix A, showing that ten of the 16 parameters in $\mathbf{A}_1$ and $\mathbf{A}_2$ could be identified during estimation. Keane (1993) also pointed out that it is difficult to identify a large number of parameters numerically in these matrices. Nevertheless, the error structure found in the $\mathbf{A}_1$ and $\mathbf{A}_2$ is sufficiently general to control for individual effects and serial correlation of the errors. The parameters in $\mathbf{A}_1$ and $\mathbf{A}_2$ are jointly significant at the critical 5% level.

The SML-estimates in Table 4.2 support, but not on very strong statistical grounds, that increasing energy prices increase the probability of adoption of co-generator with storage but decrease the probability of adoption of energy storage. A priori it was expected that increasing energy prices encourage investments in both energy saving technologies. The result that storage investments are decreasing in energy prices is, in fact, an indication that investments in co-generators become more appealing when energy prices increase. More than half (55%) of the vegetable farms that switched to co-generator during the study period already had energy storage. Therefore, increasing energy prices may decrease the probability of adopting storage combined with traditional heating because firms are then more eager to switch into (more energy saving) co-generators. Thus, the results implies that increasing energy prices, *e.g.* through a tax on energy encourage firm operators to invest in technologies that are relatively more energy saving (*i.e.* co-generators).

Table 4.2. Parameter estimates in the choice equations. Simulated Maximum Likelihood (SML) model

	Estimate	Standard Error	t-ratio
Standard with Energy Storage			
Intercept	-4.971	-*	-*
Price ratio energy and output	-0.475	4.191	-0.113
Structures	-0.394	0.146	-2.701
Machinery and Installations	0.207	0.081	2.542
Labour	0.427	0.621	0.688
Firm size	0.527	0.255	2.068
Dummy vegetables	2.439	0.682	3.574
Dummy cut flowers	1.022	0.589	1.734
Co-generator with Energy Storage			
Intercept	1.417	2.147	0.685
Price ratio energy and output	0.903	2.349	0.384
Structures	-0.781	0.402	-1.944
Machinery and Installations	1.245	0.348	3.578
Labour	1.900	0.257	3.606
Firm size	-0.842	0.405	-2.079
Dummy vegetables	-0.484	0.271	-1.790
Dummy cut flowers	-0.034	0.239	-0.143

* Parameter was fixed when inverting the Hessian matrix.

The estimates in Table 4.2 also suggest that the firm's capital stock and its allocation has significant effects on investments in energy saving technologies. The probability of adopting energy saving heating technologies decreases significantly with capital in structures, such as glass

houses. The result indicates that incentives to invest in energy saving heating technologies are higher for firms with small stocks of capital in invested in structures. The results may also imply that it is optimal first to depreciate the capital invested in structures before investing in new heating systems.

Capital invested in machinery and installations has a positive and significant effect on adoption of energy storage and a co-generator with energy storage. Therefore, firms with a larger stock of capital invested in machinery and installations are also more likely to make an additional investment by adopting a co-generator with storage.

Vegetable firms and cut flower firms more likely adopt standard heating with storage than pot plant firms do. However, vegetables firms have smaller probability of adopting co-generators (significant at 8%) than all other firm types. Firm size is increasing the probability of investing in heating storage but is decreasing the probability of investing in co-generators. Therefore, scale economies are important in getting benefits from the heat storage but co-generators are technologies that are sufficiently flexible to generate benefits in small firms.

Parameters estimated by the SML-method differ from the corresponding parameters estimated by the multinomial Logit model (see Tables 4.2 and 4.3). Firm size has a negative impact on investments in co-generators in the multinomial logit model and a positive impact in the SML model. Another difference is that vegetables firms have a lower probability of adopting co-generators in the SML model, whereas the impact is insignificant in the multinomial model. The joint significance of the parameters in $\mathbf{A}_1$ and $\mathbf{A}_2$ and the differences found here suggest that firm specific individual effects and serial correlation in the error terms play an important role in investments and choices of heating technologies.

The mean log likelihood function had value –0.411 in the SML-model and –0.430 in the Multinomial Logit model. In the restricted model, including only the intercepts, the corresponding values were -0.713 and -0.697. The goodness of fit of the SML and Multinomial Logit model is assessed using McFadden's R^2 for the system of two choice equations[6]. Values of 0.42 and 0.38 are found for the SML and Multinomial Logit models, respectively. These values indicate that the goodness of fit of the SML is rather good, in particular when taking into account the common problem of modelling low frequency decisions (*e.g.* Dorfman 1996).

Elasticities of the choice probabilities to changes in the model variables are found in Table 4.4. The elasticities indicate the relative impact of changes in model variables on the choice probabilities of different technologies; *i.e.* the impact is corrected for the measurement scale of the variables. The parameter estimates in Table 4.2 are not

corrected for the measurement scale of the variables. At the sample means of the model variables, the choice probabilities of traditional, traditional with storage and co-generator are 90%, 3% and 7%, respectively. The elasticity estimates indicate that the price of energy has a large positive impact on the probability of adopting a co-generator; the probability of adopting traditional heating and storage decreases, although the effect is substantially smaller in absolute terms. The probability of investments in traditional with storage and co-generator decrease elastically with respect to the amount of capital in the structures. Capital invested in machinery and installations has a large positive impact on the adoption of a co-generator, whereas the impact on traditional and traditional with storage is more inelastic. The probability of investing in co-generators increases elastically with labour but decreases with firm size.

Table 4.3. Parameter estimates in the choice equations. Multinomial Logit model

	Estimate	Standard Error	t-ratio
Standard with Energy Storage			
Intercept	0	-*	-*
Price ratio energy and output	-0.698	2.838	-0.246
Structures	-0.487	0.537	-0.907
Machinery and Installations	0.980	0.479	2.047
Labour	2.853	0.727	3.922
Firm size	-1.855	0.217	-8.549
Dummy vegetables	3.872	0.392	9.887
Dummy cut flowers	1.140	0.446	2.556
Co-generator with Energy Storage			
Intercept	-5.209	2.373	-2.195
Price ratio energy and output	1.996	2.525	0.791
Structures	-2.092	0.497	-4.208
Machinery and Installations	2.743	0.525	5.223
Labour	3.797	0.575	6.598
Firm size	-1.444	0.592	-2.438
Dummy vegetables	0.312	0.493	0.634
Dummy cut flowers	-0.049	0.383	-0.128

* Parameter was fixed.

6. CONCLUSION AND DISCUSSION

This chapter has applied a Monte Carlo simulation technique to estimate energy saving technology choices by Dutch glass house firms. The estimation technique allows for serially correlated errors and firm specific effects in modelling choices and is applied to panel data over the period

1991-1995. Also, a standard multinomial Logit model was estimated. The parameter estimates differ between these two specifications suggesting serially correlated errors and firm specific effects have important implications in modelling switches towards energy saving heating technologies.

Table 4.4. Elasticity estimates evaluated at the sample means[a]

Elasticity with respect to	Technology choice		
	Traditional, No storage	Traditional with storage	Co-generator
Price ratio energy and output	-0.09	-1.07	1.76
Structures	0.14	-0.89	-1.50
Machinery and Installations	-0.19	0.47	2.43
Labour	-0.30	0.97	3.73
Firm size	0.08	1.19	-1.62

[a] See Table 4.1 for sample means of model variables. Elasticities computed using the SML-estimates given in Table 4.2.

The results show that an increase of the price of energy encourages the adoption of a highly energy efficient energy saving technology (*i.e.* co-generators combined with heat storage), but discourages the adoption of heat storage. This result implies that an *ad valorem* tax on energy[7] would enhance the adoption of co-generators in combination with heat storage. The results also show that adoption of new heating technologies depends on firm capital and capital allocation. Incentives to invest in new heating technologies increase with low levels of capital in structures. Capital in heating technologies and structures are substitutes such that incentives to invest in energy saving heating technologies are higher at firms with a small stock of investments in structures. Firms that have already invested much in machinery and installations have a larger probability of adopting a co-generator than firms with low initial investments in machinery and installations. Firm size has a positive impact on investments in storage and a negative impact on investments in co-generators implying that scale economies are more important in investments in storage than in co-generators. The probability of investing in different energy saving technologies differs across firm types.

The method of Simulated Maximum Likelihood that was adopted in this chapter allows for an error structure, with random effects and serial correlation. The random effects specification accounts for unobservable variables related to the firm operator and firm thereby exploiting the panel data that were available in this study. Firm operator specific factors are *e.g.*

the management level and personal preferences. Firm specific effects are related to the location of the firm (affecting climate and access and availability of hired labour) and the firm financial structure. Serial correlation accounts for adjustment costs that cause a persistence of technology choices over time. A problem with the Simulated Maximum Likelihood method in this study was that not all parameters reflecting the proposed error structure could be identified.

Future research should extend the scope of the research by modelling the choice of the technology *and* the size of the required investment simultaneously. Different results may be expected, if required investments substantially differ between technologies. Furthermore, future research should pay attention to the role of other factors in analysing technology choice decisions and in particular to the role of information. In a situation where investments are (partly) irreversible and where the firm operator has the possibility to postpone the investment, information that reduces uncertainty may give rise to an option value (Dixit and Pindyck, 1994). Such an option value implicitly increases the costs of investments and may hamper the adoption of new (energy saving) technologies.

NOTES

[1]Co-generators produce electricity and heat simultaneously.

[2]In the literature, computational problems of solving the structural model are reduced by using convenient functional forms for the reward functions and error distributions (*e.g.* Rust 1987), or by using simulation and interpolation techniques (Keane and Wolpin 1994) and methods that do not require a full solution of the dynamic programming model (Hotz and Miller 1993).

[3]The accuracy of the reduced form approximation is a standard functional specification problem. Approximation error can be decreased by using flexible functional forms. However, in the empirical application of this chapter, augmenting the model by quadratic terms resulted in numerical identification problems.

[4]The specification in (4.5) is consistent with irreversible and reversible investments, since the estimation method maximizes the likelihood of the observed technology choices. Therefore, the reversibility or irreversibility of investments will show up in the parameter estimates.

[5]Other energy saving options available in horticulture at present are heat pump and heat deliveries by electricity plants. However, these options were used by none and only few firms in the sample period, respectively.

[6]McFadden's R^2 is calculated as: $1 - \frac{\log L(\beta)}{\log L_0}$ where $\log L_0$ is the value of log-likelihood function subject to the constraint that all regression coefficients except the constant term are zero, and $\log L(\beta)$ is the maximum value of the log-likelihood function without constraints (Veall and Zimmerman 1996). McFadden R^2 in the range of 0.2 to 0.4 are typical for logit models (Sonka *et al.* 1989).

[7]An ad valorem tax on energy increases the price that energy users pay by a given percentage.

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APPENDIX A: ERROR STRUCTURE PARAMETER ESTIMATES

Table A.1. Elements[a] of matrices A_1 and A_2

Matrix A_1		Matrix A_2	
Element[b] A_{ijh}	Estimate	Element[b] A_{ijh}	Estimate
A_{122}	0.000	A_{222}	0.238
A_{133}	1.004	A_{233}	1.257
A_{144}	1.133	A_{244}	1.504
A_{155}	1.196	A_{255}	1.417
A_{121}	-0.535	A_{221}	-0.211

[a] The other entries in the first column ($A_{131\text{-}151}$ and $A_{231\text{-}251}$) remained at their starting values 0.1.

[b] i,j,h refer to matrix number i and element j,h, respectively.

Chapter 5

ENERGY INTENSITY DECOMPOSITION IN EU AGRICULTURE, USING A DEMAND ANALYSIS

Joaquín A. Millan

1. INTRODUCTION

There are two seemingly separate strings of studies concerning sector energy use: the intensity approach and the demand approach. Both kinds of studies indicate substantial differences in the growth of energy inputs between countries and within countries for different time periods. In this chapter, a suggestion is made about how to link the intensity and the demand approaches, estimating globally well-behaved technology in intensity form (input to output ratio). The empirical part of the chapter is the comparison of the results from the estimation of intensities for the agricultural sectors of the EU countries in the 1974-96 period, according to the demand approach.

The use of energy lies behind much of the increase in agricultural output in recent times, and there is a growing literature on energy usage in agriculture. Although the importance of energy and energy based consumption in developed agricultures is recognised, little systematic evidence on the use of energy inputs in EU agriculture and or international comparisons with respect to input demands and intensities have been presented so far. Previous studies show substantial differences in the growth of energy use among countries, or even in a given country. In this context, an interesting issue arises about the comparative study of the evolution of inputs demand and intensity for the different agricultural sectors of the EU countries using a common methodology. If there are common patterns in the use of energy and energy-based inputs in EU agriculture, then general proposals for agricultural and environmental policies are advisable. If it is the case that environmental and agricultural developments concerning energy are

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country-specific, apart from the dependence on exogenous energy prices, there is less scope for general recommendations.

There are many diverse approaches to the analysis of energy intensity. An important body of literature is inter-sectoral as in input-output analysis or computable general equilibrium modelling, which are not reviewed here. Concerning partial sector analysis, there are two main, seemingly separate, strings of studies. These are namely the intensity approach and the demand approach. Papers on the intensity approach consist of decomposing energy-output ratios in a variety of effects. An extension of this kind of approach is based on index numbers or growth accounting methodologies, combining simple measurement techniques with a formal theoretical justification of the decompositions. Studies in the demand approach are based on the estimation of econometric demand systems and focus on substitution between input pairs, and output and technical change effects. Both kinds of study indicate substantial differences in the growth of energy inputs between, and within, countries for different periods.

The purpose of this chapter is to investigate the characteristics of energy usage in the EU agricultural industry by estimating the effects of fixed inputs and technical change on the composition of inputs used, and analysing the evolution of input-output ratios, or intensities. The empirical part of the chapter is the estimation of separate demand systems in intensity form for the agricultural industries of the European Union countries in the 1974-96 period. The scope of this chapter is largely determined by the availability of data. Since there are no reliable statistics with which to characterise and aggregate fixed inputs, such as land or agricultural labour, on a common basis over the period analysed, the estimation of restricted cost functions is chosen for the representation of the structure of the technology.

The generalised McFadden is used because it can be estimated on input to output ratios or intensity form, and global concavity can be imposed without restricting flexibility. The estimation of a correct economic structure in the regression of intensities allows for a theoretically sound decomposition of input intensity. This is the way of linking the two separate literatures of energy intensity and energy demand. Intensities are studied directly in the regression equations. This approach literally takes ‘ease of interpretation of parameters’ for selecting among functional forms in Fuss *et al.* (1978).

In Section 2, the different approaches to energy intensity measurement are presented, and the combined methodology used in this chapter is explained. Data and results from the estimated demand systems are presented in Section 3. The decomposition analysis of energy and energy based inputs intensities, with comments on the main results, follows in Section 4. The conclusions and some suggestions for further research finish the chapter.

2. THE ANALYSIS OF ENERGY INTENSITY AT A SECTORAL LEVEL

2.1 Decomposition of intensity indexes

The first approach is the formulation of ad-hoc decompositions, which at best have the desirable properties of being mutually exclusive components (without interaction terms) and completely exhaustive. A next step is the aggregation of sector intensities using several index number formulae. These formulations separate changes in energy use into intensity (input of energy per unit of output of a given sector) and mix (differential change, in the gross output of groups or subgroups of industries). Recent advances in this approach are in Greening *et al.* (1997). These techniques are generally criticised for their lack of theoretical foundation.

A foundation for intensity indexes decompositions is based on growth accounting. Applications of growth accounting involve the use of an aggregate production function in which the effects of changing energy, material, capital and labour inputs and productivity are translated into changes in output growth. A simple reformulating to measure changes in energy productivity, as in Chan and Mountain (1990), is related to the economic theory of index numbers. Using the translog index number formula, and simple arithmetic, changes in energy intensity are explained by weighted changes in other inputs to energy ratios (substitution) and technical change. The main operational advantage in this approach and its main interpretation problem is that it assumes long-run equilibrium for all inputs and Hicks-neutral technical progress. Given that full equilibrium in agriculture is not expected, that quasi-fixed input valuation is difficult, and that technical change is not usually neutral in agriculture, the growth accounting approach is not followed in this chapter.

2.2 Derived demand approaches

Under appropriate assumptions, the econometric analysis of input demand can measure input substitution and several other effects, including technological change. The properties of these constructs, such as non-negativity, linear homogeneity and concavity, should be examined in the case of cost functions, and other structural properties, such as homotheticity and separability can also be explored. However, it is usual for production or cost functions to be used for empirical study without fully exploiting the capabilities of the econometric structure for this empirical analysis.

In fact, each input demand equation explains and forecasts the expected value of a particular variable in terms of several explanatory variables. As an example, the translog form is usually estimated in share form, and is suitable for decomposition and explanation of changes of energy shares in cost. Thus, the decomposition in Kako (1978), that uses a translog cost function, is possible without using the estimates of the elasticities. Fousekis and Pantzios (1999) have decomposed the rates of growth for the different inputs in Greek agriculture, after estimating the demand system derived from the differential approach. Some functional forms, such as the generalised McFadden, are usually estimated in input to output ratios, thus allowing for theoretically sound decompositions of input intensity effects. Again, an elasticity-based decomposition, like that in the recent work of Peeters and Surry (2000), is not needed. Additional reasons for preferring a particular functional form are in the global theoretical properties of flexible cost functions. This point is of particular interest for robustness of extrapolation. It seems very important for forecasting and policy analysis that projections hold correct theoretical properties. These are the reasons why the generalised McFadden of Diewert and Wales (1987) is an interesting prior choice of functional form for energy intensity analysis. It is estimated with dependent variables in intensity form and curvature is imposed without restricting elasticities of substitution.

2.3 The model

To capture all the above aspects in estimating changes in input demands, it is assumed that the agricultural industry in each EU country has a twice differentiable aggregate production function with constant returns to scale relating the flow of gross output (Q) to the services of four variable inputs [x_i=energy (E), energy-based (N), biological inputs (B), and all other intermediate inputs (M)] with prices p_i $(i=E,N,B,M)$ and three fixed inputs [F_k=labor (L), capital (K), land (R)]. The characterisation of intermediate consumption follows Lopez and Tung (1982).

There is a dual variable cost function which corresponds to such a production function, and which reflects the production technology. The general form for the restricted cost function with constant returns to scale is: $G = G(\mathbf{p}, \mathbf{F}/Q, t)$, where G is variable cost, $\mathbf{p}$ is the vector of variable input prices, $\mathbf{F}$ is the vector of fixed inputs, Q is the level of output, and t stands for time reflecting the state of production technology.

For reasons explained above, there is a preferred specification for the variable cost function. The symmetric generalised McFadden with the structure for fixed inputs introduced in Rask (1995) and constant returns to

scale is used in the analysis. Details about derivation of the input demand equation using Shephard's lemma are omitted. The derived demand equation for variable input x_i $(x_i = E,N,B,M)$ with fixed inputs F_k $(F_k=K,L,R)$ is, in intensity form:

$$I_i = \frac{x_i}{Q} = \beta_i + \frac{\sum_j b_{ij} p_j}{\sum_j \theta_j p_j} - \theta_i \frac{0.5 \sum_j \sum_m b_{jm} p_j p_m}{\left(\sum_j \theta_j p_j\right)^2} + \sum_k c_{ik} \frac{F_k}{Q} + d_i t \quad (5.1)$$

with exogenous coefficients θ_i defined $\Sigma_i \theta_i = 1$, being $\Sigma_j \theta_j p_j$ a price index, with symmetry constraints $b_{jm}=b_{mj}$, and linear homogeneity in prices $\Sigma_j b_{jm} p_m = 0$. In this chapter θ_i is the mean share of input *i* in variable cost.

Curvature is imposed on the matrix **B** of coefficients, by the procedure in Wiley *et al.* (1973), forming a matrix **B** = **-AA'**, with a lower triangular matrix **A** and transpose **A'**. With this reparameterisation the estimated Hessian is negative semi-definite globally without further restricting substitution possibilities.

Variations in energy intensity are studied. The estimated energy intensity is decomposed in price (substitution) effect:

$$I_p = \frac{\sum_j b_{ij} p_j}{\sum_j \theta_j p_j} - \theta_E \frac{0.5 \sum_j \sum_m b_{jm} p_j p_m}{\left(\sum_j \theta_j p_j\right)^2} \quad (5.2)$$

separate fixed inputs [capital (I_K), labor (I_L), and land (I_R)] effects:

$$I_K = c_{EK} \frac{K}{Q} \qquad I_L = c_{EL} \frac{L}{Q} \qquad I_R = c_{ER} \frac{R}{Q} \quad (5.3)$$

and trend effect:

$$I_T = d_E\, t \quad (5.4)$$

The actual energy intensity is the sum of the above effects plus the constant term, which is irrelevant in the analysis of intensity variations, and a statistical error.

The next step is the aggregation of intensities in order to capture the general evolution in EU agriculture. This exercise is interesting because there is an increasing trend towards considering the EU as a whole. Even in the case of different production structures for the different countries, a

comparison between each country and the aggregate results is useful for characterising each country's deviations from the general evolution.

Total intensity for input *i* in EU agriculture (I_i^{EU}) can be defined as a weighted sum of intensities for the individual countries *j*, where the weights are the shares of each country in EU total agricultural output:

$$I_i^{EU} = \sum_j s^j I_i^j \tag{5.5}$$

The approach used to construct the aggregated intensity suggests that there are two sources of changes in total intensity. Time variation of total intensity I^{EU} depends, on both the time variations of intensity for each individual country and of the time variation of each country's participation in agricultural output. The within-country variation measures the changes in agricultural technology for each particular country. Alternatively, the between-country variation is interpreted as being caused by factors in the evolution of the agricultural sectors of the different countries.

The following decomposition is used to examine the change in energy intensity:

$$\Delta I = \Delta\left(\frac{E}{Q}\right) = \sum_j s_{t-1}^j \,\Delta\left(\frac{E^j}{Q^j}\right) + \sum_j \frac{E_{t-1}^j}{Q_{t-1}^j}\,\Delta s_{t-1}^j = \sum_j s_{t-1}^j \,\Delta I^j + \sum_j I_{t-1}^j \,\Delta s_{t-1}^j \tag{5.6}$$

The first summation captures the intensity changes (within), and the second summation captures the structural changes in agricultural production (between). In addition, the intensity elements can be decomposed into their elements of substitution, capital, labour, land and technical change

$$\Delta I = \sum_j s_{t-1}^j \left(\Delta I_P{}^j + \Delta I_K{}^j + \Delta I_L{}^j + \Delta I_R{}^j + \Delta I_T{}^j\right) + \sum_j \left(I_{Pt-1}{}^j + I_{Kt-1}{}^j + I_{Lt-1}{}^j + I_{Rt-1}{}^j + I_{Tt-1}{}^j\right) \Delta s_{t-1}^j \tag{5.7}$$

The same procedure can be applied to any input, such as energy-based inputs (*N*). A further remark concerning units is interesting. Zarnikau (1999) has investigated the aggregation of fuels in technical units or in economic terms. Although results are generally similar, the economic terms are preferred because substitution effects due to changing relative

prices within the energy aggregate are taken into account. In addition, measuring inputs and output at constant prices, the intensities can be interpreted as technical coefficients, and the results compared with those obtained using input output approaches.

To summarise, the analysis of energy demand by econometric methods of production and cost can be extended to the analysis of time series of interest, such as intensities, based on an adequate specification of functional form. The estimation in ratio form of a well-behaved functional form according to economic structure gives a series of estimated or predicted intensities as a more direct result than the estimates of elasticities or technical change biases. Each input demand equation in intensity form (input-output ratio) is decomposed into a set of addends measuring the different economic effects responsible for the variations in intensity. This information is further embodied in more complex aggregations of energy intensity.

3. DATA AND ESTIMATION

The first goal was to quantify the changes in energy intensity in the agricultural sectors of the EU countries by measuring the changes in the composition of input to output ratio based on cost minimisation and input demand approaches. Secondly, controlling for a given basis, that is, a base year, the particular country decompositions were aggregated according to sectoral participation in the aggregate EU agricultural output.

The data series were constructed in terms of data obtained from the Economic Accounts for Agriculture in the SPEL database, except labour and land, which were obtained from other agricultural statistics by EUROSTAT. In order to calculate EU output aggregates, nominal exchange rates for all countries in the data set were also obtained from SPEL. Annual data over the 1974-96 period was compiled for each of Belgium-Luxembourg (BE), Denmark (DE), France (FR), Greece (GR), Ireland (IR), Italy (IT), the Netherlands (NE), Portugal (PO), Spain (SP), and the United Kingdom (UK). Due to lack of reliable data Germany (GE, former Federal Republic) was analysed for the 74-93 period, and in the cases of Austria (AU), Finland (FI) and Sweden (SW), the analysis was carried out for the 1979-96 period.

The output variable is agricultural production expressed in 1990 prices. Quantities of the four input variables, considered at 1990 prices, were used as the dependent variables. It is assumed that all energy, energy-based, and other intermediate inputs purchased were used within the year. Accordingly, the quantity of energy input was the aggregated expenditure

for energy, and the quantity of energy-based input was the sum of fertiliser and agricultural chemicals, expressed in 1990 constant national currencies. Inputs of biological origin (seed and feed) are aggregated in biological inputs, and other intermediate consumption is grouped in others, all in 1990 prices. The labour quantity is annual work units by hired and family labour. Capital is measured as depreciation deflated by the repair price index. Land is agricultural area in hectares.

Before the econometric analysis, a description of input usage is presented. Table 5.1 shows the mean input-output ratios for variable inputs and capital for each country. Ratios for labour and land are not presented because they are not in comparable units (awu/national currency at 1990 prices, and hectares/national currency at 1990 prices, respectively). The joint share of land and labour can be calculated as 1 minus the sum of the included input-output ratios. There are important differences in input intensities between countries, suggesting different agricultural technologies. Although there is a positive correlation between mean energy ratios and mean ratios for the other inputs, this is not statistically significant.

Table 5.1. Ratios input-output, 1990 prices

Country	Energy	Energy based	Biological inputs	Other intermediate	Capital
AU	0.056	0.058	0.099	0.145	0.260
BE	0.041	0.064	0.289	0.130	0.077
DE	0.032	0.073	0.279	0.127	0.127
FI	0.050	0.076	0.323	0.156	0.206
FR	0.043	0.101	0.187	0.112	0.100
GE	0.082	0.078	0.213	0.149	0.205
GR	0.040	0.034	0.087	0.059	0.042
IR	0.053	0.091	0.194	0.092	0.115
IT	0.030	0.046	0.166	0.024	0.183
NE	0.048	0.042	0.275	0.107	0.092
PO	0.045	0.069	0.254	0.049	0.028
SP	0.011	0.051	0.209	0.140	0.086
SW	0.065	0.084	0.276	0.210	0.190
UK	0.047	0.086	0.234	0.172	0.142

The growth rates for output and the different inputs are presented in Table 5.2. The decline in energy for Sweden and the United Kingdom and the strong increase for Greece, Spain and Italy, are remarkable. For energy based inputs, it is worth noting the increase for Spain, and the decline for Sweden and Netherlands. In general, Spain, Greece, and Italy increased their consumption of intermediate inputs, and Austria, Sweden

and Finland exhibited a decline in global intermediate input. There are increases in capital for all countries, except Sweden, the United Kingdom, Finland and Portugal. Labour decreased for all countries, but mainly in Spain and Finland. The decline in land use is generally small.

Table 5.2. Mean rates of growth %

Country	Output	Energy	Energy based	Biological inputs	Other inter-mediate	Capital	Labour	Land
AU	0.4	0.0	-1.4	-1.2	0.7	0.3	-3.8	-0.4
BE	1.3	1.6	1.2	1.5	2.3	0.9	-2.8	-0.4
DE	1.5	0.9	0.0	2.4	0.6	0.4	-3.6	-0.4
FI	0.2	0.0	-0.5	-1.1	1.1	-0.8	-4.5	-1.2
FR	1.8	-0.1	1.4	1.8	0.7	0.7	-3.2	-0.3
GE	1.5	0.9	0.6	2.3	0.1	0.4	-3.4	1.5
GR	1.1	5.1	2.6	1.4	1.7	3.4	-2.4	0.0
IR	2.1	2.9	2.5	4.2	2.2	1.2	-1.8	-0.4
IT	1.1	3.1	1.0	1.2	0.4	3.4	-3.0	-0.8
NE	2.3	2.3	-1.8	1.9	2.5	5.0	-1.1	-0.3
PO	1.9	2.3	-1.1	-0.2	-2.5	-0.7	-3.8	0.0
SP	1.8	3.8	4.2	3.7	1.5	1.3	-4.5	-0.4
SW	0.0	-1.0	-2.8	-0.6	-0.8	-1.4	-3.1	-1.0
UK	0.9	-1.1	1.7	0.7	0.6	-1.2	-1.6	-0.9

Differences between input growth and output growth in Table 5.2 measure growth rates in intensities. A decline in intensity is interpreted alternatively as a rise in partial productivity. It is generally agreed that intermediate consumption productivity remains at constant level, the increase in total factor productivity being due to an increase in labour productivity (OECD, 1995). Although the comment on intermediate consumption is perhaps right in mean, this is not found to be the general case, because the intensity of intermediate consumption has no regular pattern of change. A diversity of patterns emerges with respect to the intensification of intermediate consumption. Only Ireland showed increases in input intensities for all variable inputs.

Despite these heterogeneous patterns, two recognisable clusters of countries were identified concerning both energy and energy based inputs. The first group comprises Greece, Ireland and Spain, showing that factor intensities increase. The second group, consisting of Austria, Denmark, Finland, France, Germany and Sweden, shows a consistent decrease in input intensities.

Based on the previous findings, the methodology explained in Section 2.3 was applied. The analytical approach implemented rests upon

two assumptions. First, technologies are not fixed across countries, meaning that the different countries are using different technical/technological processes. Second, technologies are evolving in time, meaning that the analysis is able to capture input-saving or input-using technological progress, which may have occurred during the period analysed.

The demand systems of four variable inputs in intensity form derived from the variable generalised McFadden cost function, with concavity imposed, were estimated using maximum likelihood. Table 5.3 includes a statistical summary of the estimated models. The results show that the fits are fairly good with the exception of energy-based for France and Italy.[1]

Table 5.3. Summary of estimation results

	Log-likelihood	R^2 Energy	R^2 Energy based	DW Energy	DW Energy based
AU	359.61	0.94	0.86	1.88	1.97
BE	437.30	0.88	0.72	1.60	1.07
DE	354.91	0.74	0.84	1.05	1.00
FI	267.34	0.53	0.66	2.36	1.28
FR	443.12	0.98	0.29	1.41	1.35
GE	379.35	0.95	0.75	1.91	1.57
GR	458.98	0.99	0.77	1.98	1.90
IR	400.52	0.77	0.59	2.26	2.05
IT	458.44	0.98	0.12	1.24	0.75
NE	401.79	0.66	0.96	1.19	1.89
PO	368.10	0.71	0.94	2.02	1.15
SP	427.91	0.78	0.81	1.21	1.20
SW	275.99	0.81	0.84	2.23	1.64
UK	383.91	0.98	0.64	2.11	1.15

4. INTENSITY ANALYSIS

The comparison of the decomposition of intensities clearly reflects the dissimilarities. Table 5.4 shows the decomposition of changes in energy intensity and energy-based intensity, measured as the values in 1996 (1993 for Germany) less the values in 1974 (1979 for Austria, Finland and Sweden). Almost all possible combination of effects are presented.

The general decline in labour intensity leads to an important decline in energy intensity for many countries, but with very important increases in energy intensity for Spain, the Netherlands, and Denmark.

Table 5.4. Changes in energy intensity and energy based intensity effects %

	ENERGY INTENSITY EFFECTS					ENERGY BASED INTENSITY EFFECTS				
Country	Price	Capital	Labour	Land	Trend	Price	Capital	Labour	Land	Trend
AU	-0.12	0.19	-4.12	0.03	3.28	0.31	0.44	-1.95	-1.01	0.62
BE	0.51	-0.27	-1.16	0.23	0.82	-0.58	-0.58	-0.84	-0.12	1.96
DE	0.51	-0.06	1.37	-1.56	-0.87	-0.92	-1.84	0.02	3.24	-2.55
FI	-0.07	-0.11	-3.04	0.10	2.58	0.52	-1.40	-0.87	1.40	0.47
FR	-0.22	-0.16	-2.53	0.31	0.92	0.08	0.44	7.69	-2.95	-6.16
GE	-0.14	-2.22	-0.45	0.01	1.86	-0.14	-3.69	0.23	0.07	2.20
GR	-0.05	0.26	-0.24	-1.04	4.21	0.14	0.66	-0.31	-0.43	1.09
IR	-1.93	1.06	-1.26	2.75	-1.08	-0.77	0.01	6.70	-5.25	-4.45
IT	-0.92	-0.88	-1.37	-1.75	5.85	-0.16	-1.14	3.41	-3.94	3.34
NE	-0.43	0.12	1.66	-1.47	1.62	-0.09	-0.16	2.00	-0.65	-1.15
PO	0.08	-0.56	0.00	-0.01	0.94	-1.08	-1.01	-3.57	0.78	1.09
SP	0.02	-0.06	1.40	-0.77	-0.26	0.41	-0.30	2.97	0.94	-1.52
SW	-1.44	-2.12	-2.80	0.15	4.25	-2.16	2.00	-6.06	1.62	0.05
UK	-0.85	0.20	-3.57	-0.04	1.93	0.96	-0.86	9.17	-2.38	-6.19

For these three countries, the effect of slight changes in land intensity result in a decrease of the energy intensity. The trend effect results in an increase in energy intensity, except for Spain, Denmark and Ireland. Variable input price and capital effects are in general of lesser importance.

Dissimilarities can be observed for energy-based inputs, too. There are very large increases in energy-based intensity due to labour in Ireland and the United Kingdom, and smaller increases in France and Spain. On the contrary, the effect is decreasing for Sweden and Portugal. Land and trend effects also show a variety of patterns. It is worth noting that the 'clusters' identified in the descriptive evolution of energy and energy-based inputs do not hold in the detailed analysis of the separate effects.

The explanation of the variety of results found at the national level probably lies in factors that go beyond the scope of this chapter. It is recognised that the countries in the sample have evolved in quite diverse ways, that their agriculture differs in levels of modernisation and that environmental problems and concerns are not the same. This is also related to the fact that these countries have different structural characteristics, and dealing with energy and environmental issues requires a separate analysis of each country.

Despite the observation of such varied patterns of evolution, it is worth considering the evolution of energy intensity for EU agriculture as a whole, in accordance with to recent trends characterising EU agriculture as a block. Moreover, a comparison between each country and the aggregate results sheds light on each country's particular evolution. Thus, the next step of the analysis is the aggregation of the individual country results in a series of EU intensities.

All output data, originally reported in current values of local currencies was first converted into ECUs, using the exchange rates in SPEL, and then the output share of each country was used as a weight in aggregating over EU agriculture. Given data limitations, the period of analysis is 1979-1993. The actual intensities for energy and energy based inputs are summarised in a pair of series of energy and energy-based EU intensities, using formula (5.5).

It follows from equation (5.6) that the rate of change in total intensity has two parts: the composition effect (between) and the intensity effect (within). The composition effect reflects the change in intensity resulting from changes in agricultural output from the different countries (the product of the intensity of country and the corresponding rate of change in output share, summed across all countries). The intensity effect represents the expansion or contraction of intensity directly proportional to the aggregate agricultural activity holding composition constant (the rate of change in aggregate output).

Firstly, the actual intensities are decomposed in between and within effects, using equation (5.6). In a second step, the different elements of the estimated intensities are composed with equation (5.7). It is worth noting that although labour and land intensities are measured in different units, their contributions to energy and energy-based inputs intensities are measured in the latter intensities units.

Table 5.5 shows the actual changes in energy intensity and their estimated decompositions for EU agriculture. Differences between actual ratios and the sum of their components are due to random effects in the estimated equations. There is a small decline in energy intensity, mainly in the period following the oil crisis at the beginning of the 80s. The results indicate that the lion's share is due to the 'within' element or true intensity changes. However, the trend effect is toward energy intensification, and this effect has dominated since the mid-80s. Except for land, only Italy and Sweden show an evolution of effects qualitatively similar to the aggregate. The pattern in Ireland and Denmark is very different from the average.

Table 5.5. Changes in energy intensity effects, %, EU aggregate

TOTAL	Actual	Price	Capital	Labour	Land	Trend
80-93	-0.32	-0.13	-0.37	-0.57	-0.14	0.91
80-84	-0.59	-0.22	-0.33	-0.19	-0.03	0.32
85-89	0.22	0.19	-0.07	-0.23	-0.04	0.33
90-93	0.05	-0.10	0.03	-0.14	-0.07	0.25
WITHIN	Actual	Price	Capital	Labour	Land	Trend
80-93	-0.27	-0.22	-0.30	-0.55	-0.10	0.91
80-84	-0.54	-0.23	-0.19	-0.30	-0.02	0.33
85-89	0.32	0.16	-0.02	-0.15	-0.04	0.32
90-93	-0.05	-0.15	-0.10	-0.10	-0.04	0.25
BETWEEN	Actual	Price	Capital	Labour	Land	Trend
80-93	0.00	0.08	-0.05	-0.01	-0.02	0.00
80-84	-0.02	0.01	-0.14	0.11	0.00	-0.01
85-89	-0.08	0.03	-0.04	-0.08	0.00	0.01
90-93	0.11	0.04	0.13	-0.04	-0.03	0.00

In Table 5.6, the changes in energy based inputs intensity for the aggregate EU agriculture are summarised. Again, the within decomposition accounts for most of the total effect. Here, the trend is negative, as are the effects of land and capital. However, energy-based inputs are substituted for labour, increasing the energy-based intensity. The general effect is negative, mainly in the nineties. It is remarkable that no country presents the same effect pattern as the EU aggregate qualitatively, *i.e.* considering the signs.

Table 5.6. Changes in energy-based intensity effects, %, EU aggregate

TOTAL	Actual	Price	Capital	Labour	Land	Trend
80-93	-1.55	-0.30	-0.71	1.90	-0.48	-1.28
80-84	-0.26	0.19	-0.44	0.83	-0.09	-0.44
85-89	0.22	-0.09	-0.28	0.68	-0.17	-0.48
90-93	-1.51	-0.39	0.01	0.39	-0.22	-0.36
WITHIN	Actual	Price	Capital	Labour	Land	Trend
80-93	-1.36	-0.03	-0.69	1.91	-0.60	-1.33
80-84	-0.20	0.04	-0.27	1.02	-0.22	-0.48
85-89	0.31	0.01	-0.18	0.52	-0.15	-0.48
90-93	-1.47	-0.07	-0.24	0.37	-0.23	-0.37
BETWEEN	Actual	Price	Capital	Labour	Land	Trend
80-93	-0.14	-0.28	0.02	-0.04	0.11	0.04
80-84	-0.03	0.15	-0.16	-0.22	0.14	0.05
85-89	-0.07	-0.10	-0.08	0.16	-0.04	-0.01
90-93	-0.03	-0.33	0.26	0.02	0.01	0.00

5. CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

In this application, energy and energy based intensities are estimated separately for each of the EU countries, and further aggregated in a natural way that highlights variations in structure and intensity. The evolution of energy and energy based intensities for EU agriculture is of variable signs and magnitude. The decomposition of input intensities show that, in general, price effects have a very limited contribution to changes in energy intensity, and even less in energy-based input intensity, relative to quasi-fixed inputs and technical change effects. The results suggest the difficulties involving general directions of policy opportunities for agricultural developments concerning energy as each country effects are very different from the average.

Thus, a very usual pattern in the evolution is towards decreases in energy intensity and, more pronounced, energy-based inputs intensity. The larger decline in energy-based input intensity is a consequence of the different signs of the trend effects: intensity decreasing for energy based inputs and intensity increasing for energy, in general. However, the particular composition of price, capital and labour effects is very variable.

With regard to energy intensity, if the evolution after the current oil crisis mimics the evolution in the early 80s, then the effect will be a decrease in energy intensity, with minor adjustments due to short-run

responses to intermediate consumption prices. This is in complete agreement with the results based on the analysis of inelastic factor demands and low elasticities of substitution.

For energy based inputs, the conclusions are quite different for different countries. This is in accordance with the different elasticities for fertiliser demand found in the literature. Glass and McGillop (1990) find substitutability between fertilisers and capital for Irish agriculture, and agrichemicals and capital are found to be complements for Greek agriculture by Fousekis and Pantzios (1999). In addition, the aggregate analysis in this chapter finishes in 1993, so it is possible that the described evolutions for intensities have changed since that date. This is suggested because the expansion of organic crop production has mainly taken place with the implementation of EC Regulations 2092/92 and No. 2078/92 on organic farming.

Two remarks about the ways that the model presented in this chapter could be further developed. The first is about the method of forecasting energy intensities in given future dates. The global curvature of the generalised McFadden form increases the robustness of the extrapolations since it ensures estimates of future energy intensities that have theoretically correct base. The second point is that the suggested approach can be adapted to the multiple output case, following the characterisation of outputs in Peeters and Surry (2000). Of course, each country's intensity is the result of both the particular structure of crops and animal production, and the intensities for each crop and animal production. The output aggregates used in this chapter, following SPEL, are calculated in a way similar to the output aggregate in Peeters and Surry. Moreover, the aggregation used with countries in this chapter can be used for aggregating separate crops and animal productions in case of input nonjoinmess.

Finally, the answer to the empirical question formulated in the introduction is clear. The descriptive analysis in this chapter clearly shows that there are no common patterns in the use of energy and energy-based inputs in EU agriculture. General EU-wide proposals for agricultural and environmental policies are not advisable, because developments in the relationship between agriculture and energy are highly time- and country-specific.

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NOTES

[1]To measure factor substitution possibilities, the Allen and the Morishima partial elasticities of substitution were computed at all data points. The first general conclusion is that country differences are large concerning substitution and complementarity. This conclusion is reinforced with regard to the signs concerning the quasi-fixed inputs. The results, not reported, are available from the author upon request.

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Part II

Biomass production: Technical issues

Chapter 6

ENERGY USE EFFICIENCY IN BIOMASS PRODUCTION SYSTEMS

Sanderine Nonhebel

1. INTRODUCTION

Over the last three decades, energy use efficiency (kg output /MJ input) in Western agriculture has declined. This decline has been caused by an increase in the number of inputs within agricultural systems. The decline in efficiency observed in agriculture raises the question of what (from the perspective of energy use) is the best system of growing energy crops. Is this a high-input system with high yields per hectare, but with a low energy use efficiency, or a low-input system with low yields per hectare but a high energy use efficiency? Four short-rotation forestry production systems (varying from high-input to low-input systems) will be evaluated with respect to their resource use efficiency (in addition to fossil energy, solar radiation and water will be taken into account.

Plant material is produced within various agricultural systems, ranging from low-input systems in which hardly any external inputs are used to high-input systems which require large quantities of external inputs (fertilisers, pesticides, irrigation, etc.). In general, the yields in low-input systems are much lower than in high-input systems. There is no physiological difference between the production of plant material for food and the production of plant material for energy. Sometimes the same crop is even used for both purposes (rape seed, for instance). The major difference between food crops and energy crops is that energy crops have to yield energy. This implies that the energy that can be obtained from the harvested plant material must be larger than the energy required to produce the inputs. This condition does not hold for food crops: for several crops, the fossil energy required to produce the crop is much higher than the energy that can be obtained from it (*e.g.,* the production of tomatoes in greenhouses). However, since food is not only consumed for the intake of

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energy but also for its nutritional value (vitamins etc.), the value of the harvested material is not determined by its heating value only.

During the last decade, several studies have been done on the use of fossil energy in food crop production systems. These studies have been conducted at various levels of scale (comparison of organic agriculture to high-input agriculture; developments in agriculture over the last 50 years, or between countries (Naylor 1996; Kramer *et al.* 1999; Schroll 1994; Conforti and Giampietro 1997). All authors have come to the conclusion that fossil energy is used most efficiently in the low-input crop production systems.

Since there are no physiological differences between the crops, the input-output relationship for food crops can also be expected for energy crops. This would imply that fossil energy use efficiency of low-input energy crop systems is higher than the energy use efficiency in high-input crop systems. When efficient use of fossil fuels is of importance, energy crops should be grown in so-called low-input systems. However, the studies done by Uhlin (1998; 1999) on the overall (fossil and solar) energy use efficiency of the Swedish agricultural system show that overall, energy use efficiency has increased over the last three decades instead of declined. According to these results, high-input energy crop systems use energy more efficiently.

Based on the existing information on food crops, no conclusions can be drawn with respect to the consequences of choice of a particular production system on anticipated yields. This chapter examines in detail the input-output ratios within four biomass production systems. For all systems, the energy use efficiency is calculated and any differences found between the systems are explained. Finally, the results are compared with previous studies on energy efficiency of food production systems.

2. MATERIAL AND METHODS

In order to determine the efficiency of resource use, information on inputs and outputs (yield) is required. For food producing systems, this information (at various levels of scale) can be obtained from agricultural statistics (KWIN; FAO; LEI). These kinds of data were used in the food studies mentioned earlier. For energy crops, this type of data is lacking, since these crops are presently grown in only a limited number of experimental situations.

The method used here is a different one: the target-oriented approach derived from ecological production research (van Ittersum and Rabbinge 1997). In this approach, the yield level (the output) is defined

first, followed by a determination of the required inputs to reach this yield level. Here, both yields and inputs are based on crop growth relations obtained from the literature.

2.1 Description of the biomass production systems studied

In principle, all crops with higher energy yields than energy inputs can be used as energy crops. Comparative studies between various crops have shown that the production of biomass in so-called short-rotation forestry systems seems to be most promising (Lysen *et al.* 1992). This type of biomass production will consequently be evaluated here.

The system studied is a short-rotation forestry system with poplar. The trees are planted in spring with a density of 1 tree/m^2, and every fourth year the crop is harvested by coppicing and is simultaneously chipped. After the harvest, the crop re-sprouts and is harvested again four years later. It is assumed that the plantation will have a total life span of 20 years, and hence five harvests can take place. It is assumed that the production will be the same for every harvest.

The results of a study on the production possibilities for biomass crops in various European regions (Nonhebel 1997) are used as the basis of this study. In that study, yield potentials were determined with the use of a crop growth simulation model. The model was based on the linear relation between intercepted radiation and above-ground biomass production (the so-called light use efficiency derived by Monteith (1978)). A soil water balance was incorporated to simulate the effects of water shortage on crop production. The model requires monthly averages for global radiation, temperature and precipitation to simulate production (for more detailed information on the model, see Nonhebel (1997)). The model simulates potential and water-limited production.

Potential production is defined as the production that can be obtained when a crop is supplied with optimum amounts of water and nutrients and is free from pests and diseases (van Ittersum and Rabbinge 1997). Crop characteristics, air temperature and solar radiation are the only determinants of production considered. The potential yield of a crop is a measure of what can be obtained under optimum growing conditions in a particular region. The actual yields will be much lower. The yield gap (the difference between potential production and actual yields) differs per region. In the Netherlands, actual yield levels are 70% of the potential levels, while in Southern Europe they are 30 % of the potential levels (Nonhebel 1997).

Large difference in potential yields exist across Europe, varying from 12 ton/ha in the North-West to over 40 ton/ha in Portugal. These

differences are caused by differences in climate (air temperature and solar radiation). The extremes found in Nonhebel (1997) are used here to evaluate the differences in resource use efficiency between high and low-input systems.

The following production systems were defined:

N_{high}. Potential production of poplar in North Western Europe, with an annual yield of 12 ton/ha of stems and 5 ton/ha of leaves. In this part of Europe, the annual precipitation is sufficient to prevent water shortage and potential production can be achieved without irrigation. Within this production system, the crop is fertilised and crop protection measures are taken.

P_{high}. Potential production of poplar in Portugal may be 43 ton/ha/y for the stems and 18 ton/ha/y for the leaves. However, to obtain this production level, irrigation is required.

Furthermore, two low-input systems in the same climatic regions were recognised (**N_{low}, P_{low}**); the yield of these systems is estimated at 5 ton/ha/y stems (and 2 ton/ha leaves). It is assumed that this yield can be obtained without irrigation and use of pesticides.

2.2 Determination of the required inputs

All systems have to be initiated, which means that for all systems, energy is required for soil cultivation, planting and weeding. Furthermore, after each harvest (every four years) weeding has to be done in all systems. Data required to quantify the energy costs of these actions were obtained from Eriks *et al.* (1991), Lysen *et al.* (1992) and Hall *et al.* (1993).

With respect to fertilisation, only nitrogen is taken into account. Production of this nutrient requires a lot of fossil energy. The amount of nitrogen required is yield-level dependent: all nitrogen in the harvested material (stems) is replaced and some losses are taken into account. The nitrogen in the leaves is expected to remain in the system. Data from Nilson and Eckerston (1983); Eckerston and Slapokas (1990); Eriks *et al.* (1991) and Nonhebel (1997) were used. For the low-input systems, it is only at the start of the plantation that some nitrogen is required (the nitrogen in the leaves). Throughout the rest of the life span of the plantation, the annual nitrogen deposition from the air (about 25 kgN/ha) is sufficient to meet the requirements of the crop.

Furthermore, it is assumed that in high-input systems, crop protection measures take place: the crops will be sprayed with pesticides three times a year. Energy requirements for these measures were derived from Pimentel (1980) and Eriks *et al.* (1991).

In the P_{high} system, irrigation is required (495 mm/year). Energy requirements for this irrigation were determined using data from Stanhil (1981), de Koning *et al.* (1992) and Nonhebel (1997). It should be noted that the values used for nitrogen and water use efficiency are high; in practice, the values are lower.

The energy required for harvesting the crops is yield-level dependent (higher yield implies more costs for harvesting) and data from Hall (1993) were used.

For all systems, the energy requirements of the inputs over the complete life span of the plantation were determined. The energy inputs involve the direct energy required for driving a tractor and the indirect energy required to produce the material used (for instance, the nitrogen in the fertiliser).

3. RESULTS

3.1 Inputs required for various production systems

The main energy source of a crop is solar energy. Solar radiation provides the energy for photosynthesis, which is the basis of crop production. The amount available differs per climatic region. In Table 6.1, an indication is given of the incoming solar radiation for the two regions considered. The annual radiation in Portugal is nearly twice as high as in the Netherlands. Furthermore, it is essential that water be available; the average annual precipitation is also given. The precipitation levels in Portugal are much higher than in the Netherlands, although still not enough to obtain the potential growth level.

Table 6.1. Annual solar radiation and precipitation in the two regions considered

	N-W Europe	Portugal
Solar rad. (MJ/m^2)	3418	6122
Precipitation (mm)	765	1150

Source: Stol (1994); North Western Europe: weather station de Bilt; Portugal: weather station Beja

The fossil energy inputs required for the four production systems studied are summarised in Table 6.2, and involve total inputs over the complete life span of the plantation. The high-input systems require more fossil energy per hectare than the low-input systems. The inputs for

planting, weeding and crop protection (when applied) are the same for all production systems, while inputs for fertilisation and harvesting differ. The energy requirements for irrigation are huge. In production systems that are not irrigated, fertilisation and harvest are the largest energy users. The term 'fertilisation' includes the indirect energy in nitrogen and the direct energy required to distribute the nitrogen over the area. The indirect energy is about 10 times as high as the direct energy.

Table 6.2 Total fossil energy inputs (GJ) per hectare for four production systems over 20 years

System	N_{high}	N_{low}	P_{high}	P_{low}
Planting	7	7	7	7
Fertilisation	120	8	382	8
Crop protection	24		24	
Weeding	4	4	4	4
Irrigation			760	
Harvest	144	60	520	60
Total	299	79	1697	79
Per year	15	4	85	4

The main reason for the low energy requirements of the low-input systems is that most of the nitrogen used is free of costs. The crops "grow" on the nitrogen deposition, so that no fossil energy is required for the production of artificial nitrogen and none for the application of it. To produce 25 kg N costs 1.8 GJ. This amount is quite small in comparison with the total fossil energy inputs of high-input production systems (15 to 85 GJ/ha/y), but large in comparison with the inputs in low-input systems (4 GJ/ha/y).

Table 6.3. Inputs required for the production of 1 ton of biomass in the four production systems

System		N_{high}	N_{low}	P_{high}	P_{low}
Acreage	m^2/ton	833	2000	233	2000
solar rad	GJ/ton	2848	6836	1424	12244
Water	m^3/ton	638	1530	383	2300
fossil energy	GJ/ton	1.25	0.79	1.97	0.79

When inputs are recalculated to inputs per output (resource use/ton biomass, Table 6.3), a different picture is obtained. The differences

between the production systems in resource use efficiency for land, solar radiation and water are much larger (approximately 8 times) than the differences in resource use efficiency for fossil energy (only twice as large).

The $\mathbf{P_{high}}$ system is efficient with respect to use of land, solar radiation and water, but requires more fossil energy per ton of biomass than the other systems. The more efficient use of land, sun and water in comparison with the $\mathbf{N_{high}}$ system can be explained by the fact that the growing season is longer in Southern Europe. Due to the higher temperatures in that region, the growing season covers the period between March and November, while in the Netherlands, it does not start before May. The longer growing season is the main reason for the higher yields (for more details, see Nonhebel 1997). The crops in Southern Europe use a larger part of the annual solar radiation and precipitation so that their efficiency becomes higher. This high efficiency is the result of climatic conditions, which implies that values found in one region cannot be expected in other regions with other climates. The poor results of the $\mathbf{P_{low}}$ system in comparison with the $\mathbf{N_{low}}$ system can also be explained by high radiation and precipitation levels in Portugal (yields in both systems are the same while inputs are higher).

4. DISCUSSION

The main purpose of this chapter is to quantify and give reasons for varying input-output ratios in different production systems. For this purpose, the yields chosen include the extremes in yields that may occur within Europe. In order to calculate yields and inputs, assumptions are made with respect to growing conditions and so on. The situation in practice will deviate from the assumptions made here, which will lead to other yields and other input requirements. Therefore, data obtained here should not be interpreted as forecasts of input-output ratios for a biomass crop at a specific location (when poplar is grown in Portugal, the actual yields will be lower). Values found for yields and efficiencies should be considered as orders of magnitude and differences should be evaluated in terms of higher and lower and not as absolute values.

The systems chosen cover the whole range of current agricultural practices: with and without use of fertilisers, irrigation or pesticides. The yields cover the potentials attainable over Western Europe. Based on the results found in this chapter, some general remarks can be made with respect to the energy requirements for crops in different production systems.

4.1 Use of fossil energy

The energy required to grow biomass crops is higher for the high-input systems than for the low-input systems. The relative increase of the inputs is larger than the relative increase in yield so that the resource use efficiecy declines (less biomass per input). This picture is in accordance with results found in Naylor (1996), Kramer *et al.* (1999), Schroll (1994) and Conforti and Giampietro (1997).

More detailed study of the inputs shows that 'fertilisation' covers a large amount of the total fossil energy inputs of the crop. This is because of the large energy requirements of artificial fertilisers. Crops can also obtain nitrogen from other sources (for instance, manure or compost) and the energy requirements of this nitrogen are much lower. Production systems using non-artificial nitrogen sources will have a high fossil fuel use efficiency, as is shown in this study for the low-input systems (**N_{low}** and **P_{low}**). This implies that the value of fossil energy use efficiency for a production system is strongly determined by the nitrogen source used in that system. Consequently, high-input systems using manure as nitrogen source will have a high fossil fuel use efficiency (however, since artificial nitrogen is cheap and easy to apply, high-input systems using manure or compost are very scarce and no data exist).

4.2 Use of solar energy

In biomass production systems, solar energy is converted into plant material, which is used later on as an energy carrier. Therefore, the efficiency with which solar energy is converted into plant material is of interest. In Table 6.4, a comparison is made between energy inputs (both fossil and solar) and the energy yield (the heating value of wood: 18 MJ/kg). The solar energy irradiated on a hectare is about 1000 times as high as the fossil energy used for the cultivation of the crops.

Table 6.4. Energy inputs and output of the four production systems

System	Dimension[a]	N_{high}	N_{low}	P_{high}	P_{low}
yield	GJ bm/ha/y	216	90	774	90
input	GJ fos/ha/y	15	4	85	4
net yield	GJ /ha/y	201	86	689	86
solar rad	GJ sol/ha/y	34180	34180	61220	61220
eff fossil		14	23	9	23
eff solar		0.006	0.003	0.013	0.001

[a] bm= biomass, fos=fossil energy, sol= solar radiation.

In Table 6.4, the efficiency of the use of both solar and fossil energy is given. For systems at the same location, it can be concluded that higher yields imply higher solar energy use efficiency. In the $\mathbf{P_{pot}}$ system, energy yield (GJ of biomass) is 1.3% of the incoming solar radiation; in the $\mathbf{P_{low}}$ system, only 0.15%. This does not hold for systems at different locations: both low-input systems have the same yields, while the solar energy use efficiency in the $\mathbf{N_{low}}$ system is higher than in the $\mathbf{P_{low}}$ system. These differences are caused by the different climatic conditions. The $\mathbf{P_{pot}}$ system is the most efficient system for converting solar energy into biomass (in other words, Portugal is the ideal place for growing biomass).

4.3 Energy use in agriculture

Studies on energy use in agriculture were conducted to evaluate the possibilities of reducing energy use in agriculture in general. Energy use can be reduced by more efficient use of this resource. Based on the fact that energy use efficiency in low-input systems is higher, the conclusion can be drawn that a shift to low-input agriculture will lead to an energy use reduction in agriculture (since more food is produced per unit of energy). The choice of a low-input agricultural system, however, will mean that at a higher level of scale, the effect will be reversed, as the following calculation based on data obtained in this chapter shows.

Assume that yields in high and low-input systems differ by a factor of 5 (the average of the Dutch and the Portuguese systems). A change to a low-input agriculture would imply a five-fold increase in the acreage required for food production. For a high-input system, the inputs required will be in the order of magnitude of 50 GJ/ha; for a low-input system, about 5 GJ/ha. When this energy is obtained from biomass (net yield 200 GJ/ha), one hectare of biomass is enough to grow the energy required for 4 ha high-input agriculture. Overall, 5 hectares are required for the production of a certain amount of food.

The low-input system requires 4*5 hectares for the agricultural production and these 20 hectares require (20*5 GJ/ha) 100 GJ for cultivation, which implies 0.5 ha for energy. The low-input system requires 20.5 ha for the production of the same amount of food. (This value is even higher when energy is grown under low-input conditions.) When these (15.5) extra hectares are used for the production of biomass, 15.5*200 GJ of fossil energy can be saved by using high-input agricultural systems.

The results of these simple calculations are in accordance with the data given by Uhlin (1998; 1999) concerning energy use in the entire Swedish agricultural system. This implies that in order to study energy use in agricultural production systems, other indicators than fossil energy use

efficiency are required. Knowledge obtained in studies on other sustainable energy sources might be of use and variables such as payback-time or solar energy use efficiency can be incorporated.

4.4 Shift towards low-input agriculture and the consequences for energy crops

Up to now, the choice of a high-input versus a low-input system has only been evaluated in the context of its energy yield/ efficiency. It has been concluded that the high-input systems result in the highest energy yields. In reality, the choice of a high or low-input system is also determined by socio-economic factors. The cost-effectiveness of the system plays a role, as well as the social acceptance of production systems. High-input biomass production systems can be expected to have the same effects on the landscape and environment as high-input agricultural systems. In European agriculture, a shift from high-input to organic farming is observed. Based on this information, the future feasibility of large-scale high-input energy crop farming will be low. The expected shift from high-input to low-input (or organic) production systems will have a major impact on the potential of biomass as an energy source. On one hand, the low-input food production systems will require more land for the production of food, implying a reduction of the land available for energy production. Secondly, energy yields that can be obtained from these areas will be lower, since it is not likely that future production will come from high-input systems.

5. CONCLUSION

Fossil energy use efficiency is higher in low-input crop production systems than in high-input systems. This is caused by the fact that in low-input systems, a relatively large amount of the used nitrogen originates from non-fossil resources. In energy crop production systems, solar energy is converted into plant material (with the aid of fossil energy). The net (output-input) energy yield of high-input systems is much higher than the net yield from the low-input systems. The choice of a particular production system will thus have significant consequences for the energy yields that can be obtained.

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Chapter 7

YIELD INCREASES OF THE BIOMASS CROPS *SALIX VIMINALIS* AND *MISCANTHUS* × *GIGANTEUS*: A LOOK TO THE FUTURE

Leo M. Vleeshouwers

1. INTRODUCTION

Biomass is regarded as a source of renewable energy with potential for application in the future. In the Netherlands, biomass crops are projected to fulfil 1 % of the energy need in 2020 (Van den Heuvel and Gigler 1998). In analysing the possibilities and limitations of energy production from biomass, biomass yields are an important component. In most arable crops, there has been a steady increase in yield over the years, as shown by agricultural statistics. The increase is due to improved crop genetic traits and better crop management. Therefore, over a time span of 20 years, biomass crops are expected to attain higher yields than those estimated for the present. Table 7.1 summarizes predictions of future biomass crop yields made by several authors. It shows that there is quite some variation in the predictions of future yields. Part of the variation can be attributed to differences in the time span over which the yield increase was considered. Another part may be attributed to the fact that the predictions cited in Table 7.1 are based on, sometimes implicit, different assumptions. In predicting future yields, uncertainty cannot be avoided. However, an accurate description of the premises used to make the predictions may help to evaluate the uncertainties. This chapter describes two methods for prediction of future crop yields, and combines them to estimate biomass yields for *Salix viminalis* (basket willow) and *Miscanthus* × *giganteus* in the Netherlands in 2020.

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Table 7.1. Expected future trends in energy crop yields. Growth refers to stem growth in t d.m. ha^{-1} y^{-1}

author(s)	country or region	crop	present growth	year	future growth	year	annual increase (%)
Ranney et al. (1987)	USA	SRC	13	1987	17-20	1996	2.7-4.4
Andersson (1990)	Sweden	willow	-	1990	-	2000	5-7
Turhollow & Perlack (1991)	USA	poplar	11.3	1990	18.5	2010	2.5
		switchgrass	9.0	1990	14.4	2010	2.4
Hall et al. (1993)	temperate regions	biomass crops	-	-	10-15	2000-2025	-
					20-30	2025-2050	1.2-1.6
	tropical regions	biomass crops	-	-	15-20	2000-2025	-
					20-30	2025-2050	1.2-1.6
Graham et al. (1995)	USA	poplar	6.4-7.7	2000	11.4-12.6	2005	10-12
					16.8-18.0	2020	2.2-2.6
		willow	10.4	2000	15.8	2005	8.8
					20.0	2020	1.6
		switchgrass	9.1-14.8	2000	10.6-17.0	2005	2.7-3.1
					13.1-21.2	2020	1.8-1.9
Börjesson (1996)	Sweden	willow	9.3	1995	17	2015	3.0
Faaij (1997)	Netherlands	willow	11-13	2000	14-16	2015	1.4-1.6
		Miscanthus	11-12	2000	13-15	2015	1.1-1.5

2. METHODS

In this study, two methods for estimating future yields of biomass crops are used. The first method extrapolates statistical trends observed in food and fodder crops to biomass crops. In food and fodder crops, long-term records of average yields are available. By identifying the factors that have determined or affected trends, general relationships are inferred, that may also be applicable to biomass crops.

Analysis by several authors (*e.g.* Elmore 1980) of the mechanisms behind the large increase in productivity achieved in agricultural crops revealed no connection with the efficiency of the photosynthetic apparatus. The large gain in yield was largely obtained by shifting the pattern of dry matter distribution within the plant to those plant parts that are harvested (*e.g.* Gifford and Evans 1981). In biomass crops, though, a large part of the standing dry matter is used. This may limit the possibilities for yield increase by shifting dry matter distribution from non-harvestable to harvestable plant parts. A proper method seems to be comparison with food and fodder crops whose above-ground dry matter is harvested totally, or for the larger part. In this study, a comparison is made with cereals and silage maize. For cereals, statistical data are available on both grain and straw yields, so that the total above-ground dry matter can be calculated. For silage maize, production figures relate to total above-ground dry matter. Maize shares an interesting trait with *Miscanthus* in that both are C_4 grasses that have recently been introduced in north-western Europe. Statistical data on crop yields for the Netherlands are supplied by the Agricultural Economics Research Centre (LEI-DLO) (Anonymous 1954-1997).

The second method for estimating future yields of biomass crops assesses the effects of changes in physiological crop parameters on biomass production through crop growth simulation. In mechanistic models that simulate growth of biomass crops, physiological knowledge on growth and production of the crops is integrated. Crop traits that have a strong influence on biomass production and that may be crucial in plant breeding are identified. The degree to which these traits may be changed by breeding is quantified, and by changing crop parameters in growth models, the effect on growth and yield is estimated.

In the analysis of crop physiology in this study, advancing the start of the growing season and shifting the allocation pattern are the options that are explored by crop growth simulation. In the crop growth model that was used in the study (see Vleeshouwers 2001), simulated yield is determined by (1) the efficiency with which radiation is intercepted by the crop canopy, (2) the efficiency with which the intercepted radiation is

converted into biomass, and (3) the proportion of growth allocated to harvestable plant parts (*i.e.,* the harvest index). Of these three processes, increasing the efficiency of radiation interception and increasing the harvest index are the most promising avenues to increased yields. Cannell *et al.* (1987) showed that the efficiency of radiation interception is strongly increased by early establishment of the crop canopy. Whereas there is little scope for breeding for a more efficient use of the intercepted light, increased partitioning to harvestable plant parts has been a successful strategy in many crops. However, it should be noted that in biomass crops, increasing partitioning to stems may come at the cost of enlarging growth capacity through reduced partitioning to leaves.

Apart from canopy development and partitioning, other crop traits that relate to the specific production system of the biomass crops are analysed quantitatively. In *S. viminalis,* these traits determine crop duration and cutting cycle length. *S. viminalis* is a perennial crop. After 20-30 years, crop growth starts to decline and the crop is cleared. In the first years after planting, crop growth is reduced compared to that of a full-grown crop. Selecting for crop varieties that have a longer period of maximum growth and therefore allow for a longer duration of the crop, minimize the effect of reduced growth in the initial years. *S. viminalis* is harvested every 3-5 years. The time between two harvests is called the cutting cycle. In the first year after harvest, growth is reduced compared to the later years of the cutting cycle. Within a cutting cycle, growth starts to decline after 5 years (Sennerby-Forsse *et al.* 1992). Selecting for crop varieties that maintain a high growth capacity throughout a longer cutting cycle may lead to a longer period between two harvests, and thus to a higher annual biomass increment, averaged over the entire cutting cycle.

In *M.* × *giganteus,* traits that determine crop duration and winter losses are analysed. *M.* × *giganteus* is a perennial grass, which is harvested every year. Crop growth starts to decline after 10-15 years. Also for *M.*× *giganteus,* the average yield may be increased by selecting for a longer period of maximum growth. Usually, *M.* × *giganteus* is harvested at the end of winter. Stem material may be lost as a result of reallocation to rhizomes (underground plant parts) in the autumn, loss of stem tips owing to winter storms, losses during harvest operations, and biomass remaining in the stubble. Possible options to decrease these losses are breeding for stronger stems, *e.g.* by inducing crop senescence earlier in the season, in order to decrease lodging and breaking of stem tips, implementing management that prohibits lodging, and improving harvest techniques in order to minimize losses during harvest.

The statistical approach and the physiological approach are complementary methods for estimating future crop yields. The statistical

approach refers to actual yields, *i.e.* the yields obtained by farmers. It estimates the shortfall relative to potential yields, *i.e.* the yields under optimal conditions, which can be quantified by physiological crop growth models.

3. RESULTS

3.1 Analysis of statistical trends in current crops

3.1.1 Winter wheat and other cereals

As a first example for cereals, data on winter wheat are analysed. Figure 7.1 shows the increase in farmer's yield of winter wheat in the Netherlands, in terms of grain yield and total above-ground yield in the period from 1946 to 1993.

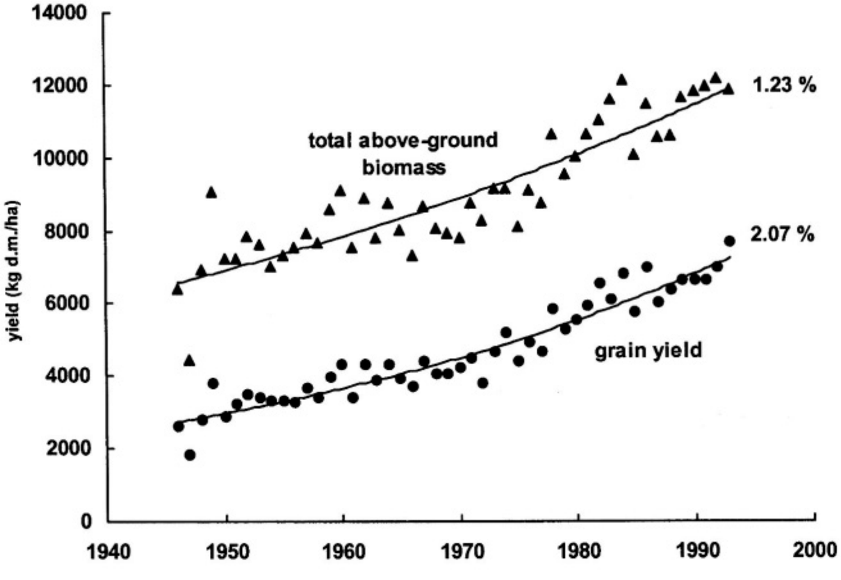

Figure 7.1. Statistical trends in the winter wheat grain and total above-ground dry matter yields in the Netherlands in the period from 1946 to 1993. In calculating the grain dry matter yield, a moisture content of 16% was assumed. Data were obtained from Anonymous (1954-1996). Exponential curves were fitted through the data

In this period grain yield of winter wheat increased exponentially with an annual rate of 2.07 %. The increase in grain yield cannot be solely

explained from the increase in total above-ground biomass, since this amounted to 1.23 %. Apparently, the remaining increase of 0.84 % per year is caused by a shift in the ratio of grain to total above-ground dry matter. Comparison with data reported by Austin *et al.* (1989) helps to interpret these trends. When winter wheat varieties introduced in the period 1830-1985 were grown under optimal conditions in the UK, Austin *et al.* (1989) found that old varieties produce the same amount of dry matter as the modern ones, *i.e.* about 15 t d.m. ha^{-1}. However, the grain mass of modem varieties made up a larger proportion of the total biomass produced. The increase of the harvest index in Dutch agriculture that can be inferred from Figure 7.1 is similar in size to that reported by Austin *et al.* (1989), and may thus be attributed to the efforts of plant breeders. The increase in the total above-ground winter wheat yield by 1.23 % in the period 1946-1993 (Figure 7.1) is caused by improved growing conditions. In C_3 crops, the rising CO_2 concentration in the atmosphere causes an increase in dry matter production by 0.2 % annually (Goudriaan and Unsworth 1990). The remaining 1.03 % is attributable to a better crop management, which allowed farmers to attain a steadily increasing fraction of the yield under optimal conditions. The ceiling for yield increase by improvements in agricultural production methods is the potential production level. The potential yield of the varieties introduced in the period 1980-1985 is 15.9 t d.m. ha^{-1} (Austin *et al.* 1989). The average actual total above-ground dry matter yield in the final 10 years of the studied period (*i.e.* 1984-1993) was 11.4 t d.m. ha^{-1} (Figure 7.1), so that farmers achieved 72 % of the potential winter wheat yield, in terms of total above-ground dry matter.

When considering all cereal crops grown in the Netherlands, there is an average annual increase of 1.7 % in grain yield. An increase by 1 % results from an increase in total above-ground dry matter, mainly by improved crop management (0.8 %, with the remaining 0.2 % owing to the increase in atmospheric CO_2), and an increase by 0.7 % results from an increase in harvest index, caused by advancements in plant breeding. Similar estimates for the relative contributions of management and breeding were made by Evans (1993), who reported that half of the yield increase over the years can be attributed to introduction of higher yielding varieties and half to improved cultural practices.

3.1.2 Silage maize

Silage maize was introduced in the Netherlands in the early 1960s, but statistical yield data are only available from 1975 onwards. Figure 7.2 shows the trend in silage maize yield on farmer’s fields in the period from

1975-1996. The average yield fluctuates around 12.1 t d.m. ha^{-1}, and the annual increase in yield (0.15 %) is not significantly different from zero. However, yields of silage maize varieties that were determined in variety trials show an annual yield increase attributable to breeding of 0.88% in the period 1954-1981 (Struik 1983).

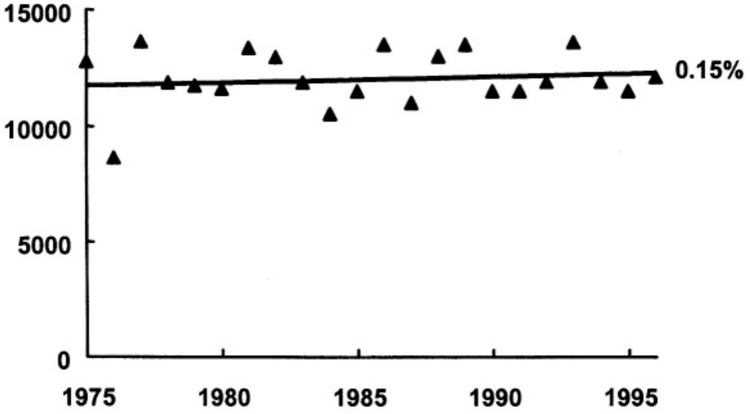

Figure 7.2. Statistical trend in the total above-ground dry matter yield of silage maize in the Netherlands in the period from 1975 to 1996. Dry matter yields in the period from 1975 to 1984 were calculated from fresh matter yields, assuming a moisture content of 27 %. Data from Anonymous (1976-1997). An exponential curve was fitted through the data

The fact that the trend in the yield of new varieties is not reflected in the actual yield data implies that the yield increase by improved cultivation techniques, which was observed in winter wheat, did not occur in silage maize. There are several possible explanations for this difference. In the Netherlands, most silage maize is not grown by specialized arable farmers, but by pig, chicken and dairy farmers, who partly rely on contract workers for their crop management. This may lead to sub-optimal crop management. Moreover, in the Netherlands, the maize crop was given very high amounts of slurry and manure, especially in the first part of the period shown in Figure 7.2. Although maize tolerates the high doses, they were often not tuned to crop requirement but rather to the amount farmers needed to dispose of. From 1987 onwards, however, legislation progressively restricted the application of slurry and manure.

Apart from the factors that may explain the absence of an increasing trend, there are also cultural and socio-economic developments

that influenced yields adversely. First, the enlargement of the area cropped with silage maize may have taken place mainly on marginal soils, with lower yield potential. Second, silage maize was practically free of diseases and pests shortly after it had been introduced to the Netherlands. Gradually, however, pests, weeds and diseases have spread, depressing silage maize yields, and counteracting the simultaneous progress made by higher yielding varieties. The two adverse developments together apparently caused a reduction in yield by 0.73 % annually, so that the net increase was only 0.15 %. Moreover, whereas cereal yield increases by 0.2 % annually owing to an increase in the atmospheric CO_2 concentration, this response is negligible in maize, being a C_4 crop.

The average yield of silage maize in the period 1975-1996 was 12.1 t d.m. ha^{-1} (Figure 7.2). According to Van der Werf *et al.* (1993) the potential yield amounts to 16.6 t d.m. ha^{-1}, so that in practice farmers achieved 73 % of the potential yield level.

The conclusion from the analysis of statistical data on cereals and silage maize is that plant breeding accounts for an annual increase in crop yield of 0.7 to 0.88 %. The effect of crop management on crop yield ranges from –0.73 % to +1.03 % per year. Biomass of the harvestable product increases by 0.15 to 2.07 % annually. The lower bound of the range applies to conditions where improvements by plant breeding are counteracted by trends in land use or pest and disease development that have adverse effects on yield; the upper bound of the range is reached when there is a synergy between breeding and management.

3.2 Analysis of crop physiology

3.2.1 Salix viminalis

Partitioning

Model calculation according to Vleeshouwers (2001), applied to the period 1968-1997 in the Netherlands, showed that the potential stem growth of a full-grown *S. viminalis* crop is 17.5 t d.m. ha^{-1} y^{-1}. Further simulation revealed that, compared to the current pattern of partitioning, final stem yield was higher when allocation to leaves was increased early in the season, and decreased later in the season. Early establishment of the leaf canopy advanced the start of radiation interception. Once the leaf canopy had been established, harvestable stem biomass was increased by maximizing the allocation to stems. The exact shape of the optimal allocation pattern, and the concomitant increase in stem yield are

dependent on model assumptions concerning leaf mortality. Simulations showed that in the Netherlands stem growth under optimal conditions would increase to 21.0 t d.m. ha^{-1} y^{-1} if the existing allocation pattern could be changed to the optimal one. There may be biological restrictions to reaching the simulated optimal pattern of dry matter partitioning completely, but the order of magnitude of the increase is such that breeding in this direction seems promising.

Prolonging crop duration and cutting cycle

In the year of planting, stem growth is negligible, and in the year after planting it reaches about 50 % of the growth of a full-grown crop. In the year after harvest, growth is reduced by about 50 % compared to the later years of the cutting cycle. Currently, a crop duration of 20 years and a cutting cycle length of 4 years is usual, so that the average stem growth is 0.825 times that of a full-grown crop (calculated as [0+0.5+1+1 + 4×(0.5+1+1+1)] / 20). Selecting for varieties that maintain a high production level both during the cutting cycle and during the life-time of the crop may lead to a higher average stem production. If we assume that in the next 20 years the crop duration can be prolonged to 30 years, and the cutting cycle length to 5 years, which are the maximum values reported to date, the average stem growth in 2020 will be 0.867 that of a full-grown crop (calculated as [0+0.5+1+1+1 + 5×(0.5+1+1+1+1)] / 30). In making estimates for crop duration and cutting cycle length, there are two qualifications that should be considered. First, mechanical harvesting techniques set a limit to the size of the stems that can be harvested and thus to the length of the cutting cycle. Second, when new higher-yielding varieties are introduced, farmers may prefer replacement of the existing crop by a new one, and not extend the duration of the current crop.

3.2.2 Miscanthus × giganteus

Partitioning

Results for *M.* × *giganteus* were largely similar to those for *S. viminalis*. Simulations for the Netherlands over the period 1968-1997 showed that the potential stem biomass production of a full-grown *M.* × *giganteus* crop is 18.9 t d.m. ha^{-1} y^{-1}, and that it may be increased to 23.1 t d.m. ha^{-1} y^{-1} by optimal partitioning.

Advancing the start of the growing season

Apart from a shift in partitioning to leaves at the beginning of the growing season, an early start of radiation interception may also be effected by low temperature requirements for leaf growth. Temperature requirements of early leaf development were evaluated in 32 genotypes from the genus *Miscanthus* (Clifton-Brown and Jones 1997). In Figure 7.3, plant extension rates (*i.e.* height growth rates) of two contrasting genotypes are shown. Based on these data, Clifton-Brown and Jones (1997) simulated potential yields of the 32 genotypes under the climatic conditions in Ireland. Differences in leaf development rates in spring had large consequences for the final biomass yield of the different *Miscanthus* genotypes: simulated yields ranged from 3 to 23 t d.m. ha^{-1}. The genotype with the highest yield (P34) is the *M.* × *giganteus* genotype that is already being used in most field trials in Europe. Therefore, it seems that the genotype with the lowest temperature requirement for leaf emergence has already been selected, and that there is little scope for yield increase in this direction.

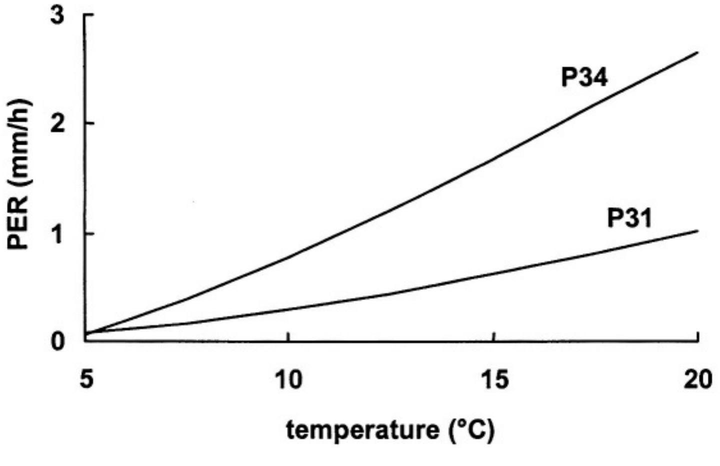

Figure 7.3. Plant extension rates (PER) of the Miscanthus genotypes M. × giganteus (P34) and M. sinensis var. Silberspinne (P31) as a function of temperature (data from Clifton-Brown and Jones 1997)

Diminishing winter losses

Reported stem losses during winter range from 0-50 % (Schwarz *et al.* 1993; Beale and Long 1995; Jørgensen 1997). In this study, the current average stem loss is assumed to be 15 %, and is assumed to decrease to 10

% in 20 years owing to breeding efforts and management improvements. The loss of leaves during winter may be preferable, since it leads to an effective recycling of nutrients within the field.

Prolonging crop duration

Only from the fourth year after planting does *M.* × *giganteus* reach its maximum yield. In the first three years, yields are 0 %, 50 %, and 90 %, respectively, of those of a full-grown crop (Ten Hag 1998). There is hardly any long-lasting experience with *M.* × *giganteus.* The projected crop duration is 10-15 years. Selecting those varieties that maintain their productivity over a long time span may lead to higher average yields. If we assume that in the next 20 years the crop duration will be prolonged from 10 to 15 years, the average crop yield would increase from 0.84 to 0.893 times that of a full-grown crop (calculated as [0+0.5+0.9+7×1] / 10 and [0+0.5+0.9+12×1] / 15, respectively).

4. YIELD ESTIMATION AND DISCUSSION

In this section, the elements from the results section are combined to derive yield estimates for *S. viminalis* and *M.* × *giganteus* in 2020. First, the starting point will be defined by estimating current actual yields. The calculations are illustrated in Figures 7.4a and 7.4b.

4.1 Current actual yield (year 2000)

At present only a few hectares of commercial *S. viminalis* and *M.* × *giganteus* are grown in the Netherlands, from which no yield data are available. Therefore, it is assumed here that the present actual stem production by *S. viminalis* and *M.* × *giganteus* would be 72.5 % of the optimal stem production. This is similar to the total above-ground yield in winter wheat and silage maize, and thus equal 0.725 * 17.5 = 12.7 t d.m. ha^{-1} y^{-1}, and 0.725 * 18.9 = 13.7 t d.m. ha^{-1} y^{-1}, respectively. During the harvest operations, and in *M.* × *giganteus* also during winter, part of the stem material is lost. Losses are estimated at 10 % in *S. viminalis,* and at 15 % in *M.* × *giganteus.* Therefore, the growth of harvestable stem biomass in a full-grown crop is 0.9 * 12.7 = 11.4 t d.m. ha^{-1} y^{-1} in *S. viminalis,* and 0.85 * 13.7 = 11.6 t d.m. ha^{-1} y^{-1} in *M.* × *giganteus.*

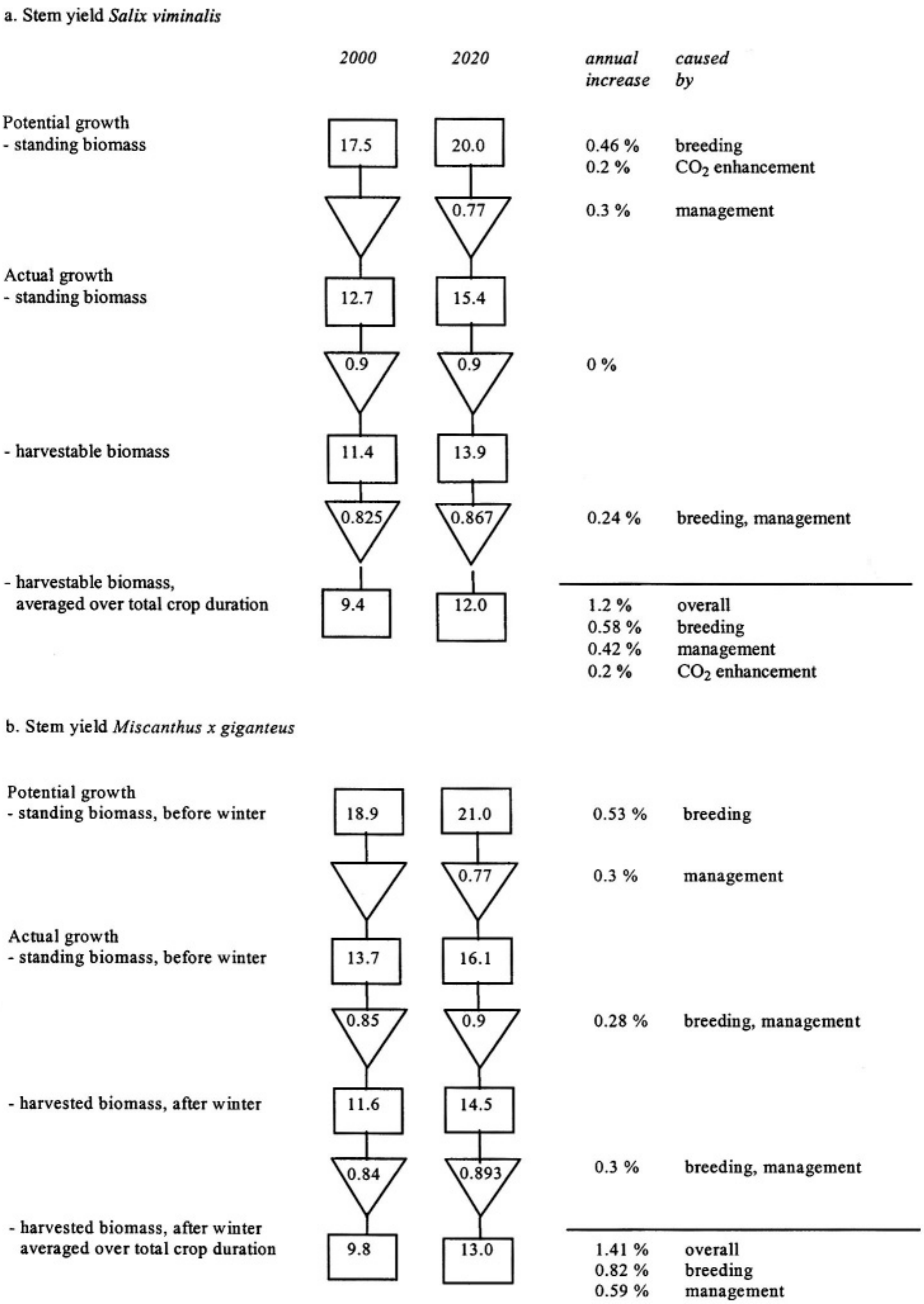

Figure 7.4. Estimation of future yield in (a) Salix viminalis and (b) M. × giganteus. Stem growth rates (t d.m. ha^{-1} y^{-1}) are given in rectangles, multiplication factors are given in triangles

In a 20 years' crop duration of *S. viminalis,* with a cutting cycle of four years, the average harvestable stem production amounts to 0.825 * 11.4 = 9.4 t d.m. ha^{-1} y^{-1} because of reductions in the initial and post-harvest years. In a 10 years' crop duration of *M.* × *giganteus,* the average harvestable stem production amounts to 0.84 * 11.6 = 9.8 t d.m. ha^{-1} y^{-1} because of reductions in the initial years.

4.2 Future development of the actual yield (year 2020)

It was assumed that breeding for an improved stem/foliage ratio in *S. viminalis* and *M.* × *giganteus* will lead to half the theoretically possible yield increase in 20 years. Therefore, under optimal conditions in 2020, one may expect a potential stem growth of a full-grown crop of 17.5 + 1.7 = 19.2 t d.m. ha^{-1} y^{-1} in *S. viminalis* in 2020, and of 18.9 + 2.1 = 21.0 t d.m. ha^{-1} y^{-1} in *M.* × *giganteus.* The additional annual increase in stem growth of 0.2 % by the enhanced CO_2 content in the atmosphere, leads to a potential stem growth of a full-grown *S. viminalis* crop of 20.0 t d.m. ha^{-1} y^{-1} in 2020.

It was assumed that both the management factors causing an annual yield increase in winter wheat of 1.03 %, and the factors causing an annual yield decrease in silage maize of 0.73 %, apply to biomass crops. Yields of biomass crops grown by arable farmers may increase by the application of knowledge that is gained through research programmes; enlargement of the area with low productive soils and the introduction of pests and diseases are possible developments that could reduce the yield increase. The resulting yield increase owing to developments in crop management would thus amount to 1.03–0.73 = 0.3 % annually, and the fraction of the potential yield attainable by farmers would increase from 0.725 to 0.77 in 20 years (0.77 is calculated as 0.725 × $[1.003]^{20}$). Resulting actual stem growth rates are 0.77 * 20.0 = 15.4 t d.m. ha^{-1} y^{-1} in *S. viminalis,* and 0.77 * 21.0 = 16.1 t d.m. ha^{-1} y^{-1} in *M.* × *giganteus.*

If it is assumed that in *M.* × *giganteus,* winter losses are reduced to 10 %, the expected yield in spring 2021 is 0.9 × 16.1 = 14.5 t d.m. ha^{-1}. In *S. viminalis,* the harvested stem fraction is assumed to be constant at 0.9, and the increment of harvestable stem biomass will amount to 0.9 * 15.4 = 13.9 t d.m. ha^{-1} y^{-1}.

Increasing the cutting cycle in *S. viminalis* to five years, and the crop duration to 30 years, increases the average harvestable stem production during the crop duration to 0.867 * 13.9 = 12.0 t d.m. ha^{-1} y^{-1}. All factors together cause an increase in stem growth from 9.4 t d.m. ha^{-1} y^{-}

[1] to 12.0 t d.m. ha^{-1} y^{-1} in 20 years, implying an annual increase rate of 1.2 %. If the crop duration of *M.* × *giganteus* could be increased to 15 years, the average stem yield in spring 2021 would be 0.893 * 14.5 = 13.0 t d.m. ha^{-1}. All developments together cause an increase in stem growth from 9.8 t d.m. ha^{-1} y^{-1} to 13.0 t d.m. ha^{-1} y^{-1} in 20 years, corresponding with an annual increase rate of 1.41 %. The order of magnitude of the annual increase rate calculated in this study corresponds with the one estimated by Hall *et al.* (1993) and Faaij (1997). However, it should be noted that the time span over which Hall *et al.* (1993) expect an average annual increase by 1.2-1.6 % is longer than the 20 years' period considered here, and the absolute yield level predicted by Faaij (1997) is higher than the one estimated here. This implies that the expectations for future yield development in this study are lower than those by Hall *et al.* (1993) and Faaij (1997). The other studies summarized in Table 7.1 present estimates for yield increases in biomass crops that are high compared to the ones calculated in this study. The more modest estimates given here seem more realistic, the more so as considerations of long-term sustainability may limit maximum yields, as argued by Hall *et al.* (1993). Taking into account the use of energy and water, and the effects of fertilizers and pesticides on the environment, aiming at maximum yields may not necessarily be the most sustainable way to produce energy from biomass crops.

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Part III

Biomass production and land use

Chapter 8

AGRICULTURAL REFERENCE SYSTEMS IN LIFE CYCLE ASSESSMENTS

Nicolai C. Jungk, Guido A. Reinhardt and Sven O. Gärtner

1. OBJECTIVE AND PROCEDURE

A life cycle analysis (LCA) for agricultural products must observe the so-called agricultural reference system in order to obtain accurate results. The reference system defines what the cultivated land area would be used for if the investigated product were not to be produced. Not considering reference systems violates the principle of 'comparing like with like' and may distort the results. The objective of the present work is to discuss and define this principle as well as others. One of these is that the geographical boundaries must be clearly defined.

The production of biomass for energy from agriculture or forestry, in comparison to the provision of fossil fuels, requires relatively large areas of land. Therefore, when a comparison is being made between a bioenergy and a fossil energy carrier, it is always necessary to define an alternative way in which the required land might be used if not for the production of energy. Any environmental assessment of a bioenergy production system has to take into account such an alternative land use, also referred to as the (agricultural) reference system. If this factor were to be ignored, the production system under concern would not be adequately represented, which would put any claim for sustainability in question. With regard to ecological impact assessments particularly of agricultural products – including bioenergy carriers – the reference system has often not been considered in the past (see for example Andersson and Ohlsson 1999; Ceuterick and Spirinckx 1997; Möhlmann 1998), or different reference systems were used for the same LCA objective (*e.g.* Biewinga and van der Bijl 1996; Reinhardt *et al.* 1999; Wolfensberger *et al.* 1997). Therefore, it was found necessary to define the role of the reference system and its

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underlying principles. This was done in detail in the study underlying the present work (Jungk and Reinhardt 2000).

The purpose of an LCA is to assess the environmental impact of every step in the life cycle of a particular product ('from cradle to grave'). This includes the necessity of defining all influences by that product with respect to an alternative product. Therefore in theory any process that involves a change in land use requires the consideration of a reference system. In the case of buildings however, such as factories or oil rigs, the land area taken up is very small in comparison to the product output, while in the case of forestry or agriculture the ratio is different, since relatively large areas are required.

It is the purpose of this chapter to provide a definition of the agricultural reference system and to deduce certain principles that should be followed in order to designate an appropriate reference system for an agricultural product. Note that land use change will not be considered as an indicator in LCA, but is the consequence of the choice of system boundaries. Furthermore, examples were chosen which demonstrate the effect of different reference systems on the environmental impacts of bioenergy carriers. These examples were based on rape seed methyl ester (RME) for biodiesel as one of the most widely used forms of bioenergy. For this purpose, complete life cycle analyses were carried out for RME and diesel from fossil fuel, which were then compared within different contexts, *i.e.* using different reference systems. The examples were calculated following the ISO 14040-41 standards (DIN EN ISO 1997 and DIN EN ISO 1998). For every example a life cycle inventory (LCI) was carried out with regard to selected parameters, and partly also a life cycle impact assessment (LCIA). These two elements are parts of a life cycle analysis (LCA). An LCA can be carried out for a single product or it can compare the life cycle impacts of two products, which was done in the examples below. Figure 8.1 is a schematic representation of a whole life cycle of an agricultural bioenergy carrier including the reference system as well as the system serving as a comparison, namely conventional diesel fuel.

2. DEFINITION AND RELEVANCE OF AGRICULTURAL REFERENCE SYSTEMS WITHIN LCA

Why is it at all necessary to take a reference system into account? The following example may clarify this point: if an LCA is to be carried out for a certain amount of rape seed methyl ester (RME) to be used as biodiesel in

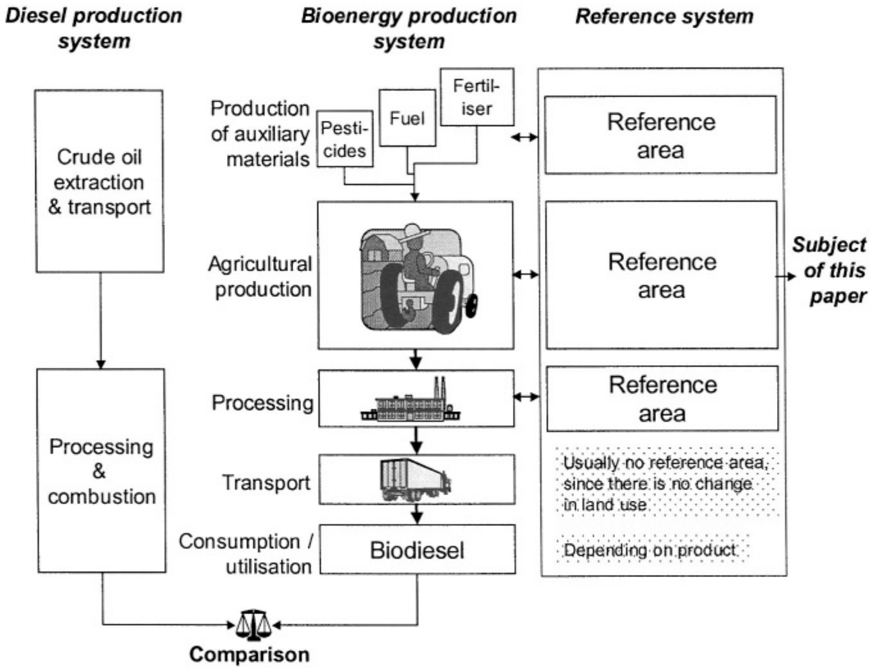

Figure 8.1. Life cycle steps of biodiesel from rape seed methyl ester (RME) in comparison with conventional diesel fuel including the agricultural reference system

order to replace diesel from fossil resources, then a certain amount of land must be cultivated with rape seed. If the RME were not to be produced, then this area could be used for cereal production. Thus an imbalance would arise: if RME is produced, fuel is produced but no cereal, whereas in the alternative case, fuel is also produced (from fossil resources), but in addition to this, cereals are produced. These two systems could therefore not be meaningfully compared in order to assess the actual environmental effects that would arise (since the 'functional unit' would be different).

If on the other hand the rape seed were grown on fallow set-aside land, then in both cases fuel only would be produced and therefore a meaningful comparison would be possible. Thus, fallow set-aside land would be a valid reference system. In the case of cereal production as an alternative land use, the question would become more complex, because it would be necessary to define where the cereals would come from if rape seed was produced. Furthermore, it would then be necessary to ask, where the product (if any) would be produced which the cereals would 'replace' and so on. Thus, a chain of land use changes could arise that may in theory be very long and complex.

In the example given in Figure 8.2, rape seed is grown instead of maize, while the maize is produced in South America where rain forest is

cleared for this purpose. This however, is only one option out of many possible ones. The exact option chosen must be implicitly defined in the question on which the LCA is based.

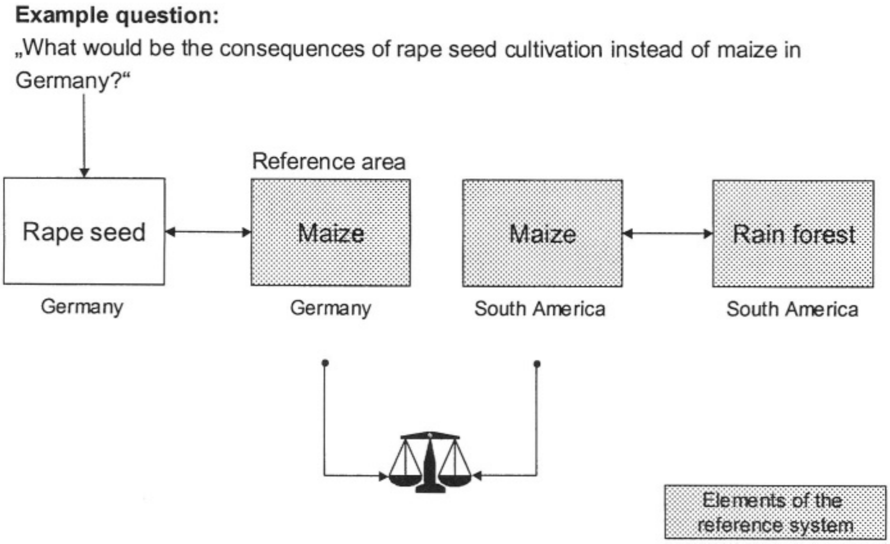

Figure 8.2. Example for a chain of land use changes. The scales indicate that the utility of the two systems indicated must be equal, i.e. in this case, the same amount of maize must be produced. Such chains can in theory be very long and complex, as can be imagined if the maize were to be produced on former sugar cane fields and so on

Thus in the example above, the exact and correct question would not be: 'What would be the environmental consequences of rape seed production in Germany?', but instead: 'What would be the environmental consequences of rape seed production in Germany, if it were to replace the production of maize and this maize were then to be produced in South America on cleared rain forest areas?'.

If instead of clearing rain forest, the maize were to be produced on sites where otherwise for example sugar cane would be cultivated, then obviously this chain would continue. We define the alternative land use on the area directly under concern as the 'reference area'. The reference *system* includes this area but in addition it includes all the land use changes that arise indirectly, as well as all emissions from transport and other processes (*e.g.* different production methods etc.). Thus it can be deduced that the reference system is closely connected to the exact question on which the LCA is based. If the question is formulated precisely, then the reference system is automatically defined.

As mentioned above, there are many possible reference systems connected to a particular 'general goal' such as assessing the environmental effects of the production of a bioenergy carrier. The reference system thus depends on the more exact phrasing of the question on which the LCA is based. Figure 8.3 gives several examples for different options regarding an LCA for RME in comparison to diesel from fossil resources.

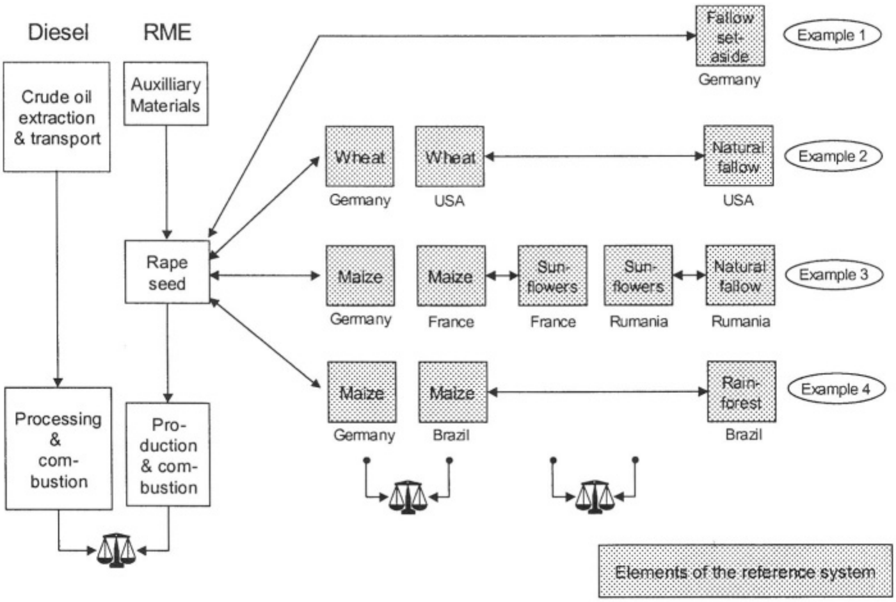

***Figure 8.3.** Example of various possible reference systems regarding an LCA for RME compared to fossil fuel*

From this it becomes clear that in order to establish an appropriate reference system it is necessary to describe the relevant scenario very precisely. This includes information on which products are to be grown on which areas and how the respective equivalent products are to be obtained. If such information is not given, in theory the LCA could be carried out using *any* feasible, but not necessarily realistic, scenario – which would inhibit a fruitful discussion about the actual environmental impacts of a given product.

Figure 8.3 also indicates that the chain of land use changes always ends either with set aside or natural fallow land (such as rain forest) or some other land use which does not lead to the production of an economic commodity.

3. EXAMPLES OF THE INFLUENCE OF AGRICULTURAL REFERENCE SYSTEMS ON CALCULATION RESULTS

The potential significance of the reference system on the quantitative results of calculations within agricultural LCAs can be shown within various different contexts (Jungk and Reinhardt 2000):

- **Different reference system options for equal LCA objectives**: the same 'general goal', such as comparing RME versus conventional diesel, can be achieved using very different reference systems, which may lead to different results (see Figure 8.3 above).
- **Different geographical boundaries**: in certain cases it may be desirable to consider only the environmental impacts produced within a particular country or area. In this case, all ecological impacts caused outside those boundaries are excluded from the calculations. The 'choice' of the reference system may then have a large impact: if most of the system is located within the defined boundaries, the impact may be very different from a situation where the main part of the system lies beyond the boundaries.
- **Different combinations of land use producing the same utilities**: different forms of agricultural practice, *e.g.* conventional and organic farming, lead to different yields. Thus the surplus areas achieved in high yield areas can be used for various purposes, such as producing bioenergy. Through different combinations of farming practices and the use of bioenergy or fossil fuels, the same commodities (food and energy) can be produced using different land covers. These combinations can all be regarded as different reference systems, leading to different results.

A detailed discussion of each of these issues lies beyond the scope of this chapter, but the examples in the following three sub-chapters shall explain the underlying issues of these points in greater depth and thus clarify some of the main principles associated with the definition of an appropriate reference system. The calculations in these examples are taken from and thoroughly explained in the study Jungk and Reinhardt (2000), which also refers to Borken *et al.* (1999), Bünger *et al.* (2000), and Reinhardt *et al.* (1999).

Of the ten impact categories generally considered within LCAs, in the examples shown here five quantifiable categories were chosen:

- Energetic resource demand (CED – cumulated energy demand regarding fossil resources, in J)
- Greenhouse effect (expressed as kg CO_2-equivalents regarding CO_2, CH_4, N_2O; IPCC 1996)

- Stratospheric ozone depletion (expressed as kg N_2O)
- Acidification (expressed as kg SO_2-equivalents regarding SO_2, NO_x, NH_3, HC1; Heijungs *et al.* 1992)
- Human and eco-toxicity: expressed as kg of SO_2, NO_x, NH_3, HC1.

3.1 Different reference system options for equal LCA objectives

In the first group of examples, biodiesel from rape seed is compared to conventional diesel, using different reference systems. For these examples, in addition one qualitatively assessed parameter was included, *i.e.* biodiversity, based on expert judgement. The results shown in Figures 8.4 and 8.5 are the overall results of complete life cycle comparisons between RME and diesel fuel, in each case taking into account all steps from oil production and processing through to combustion.

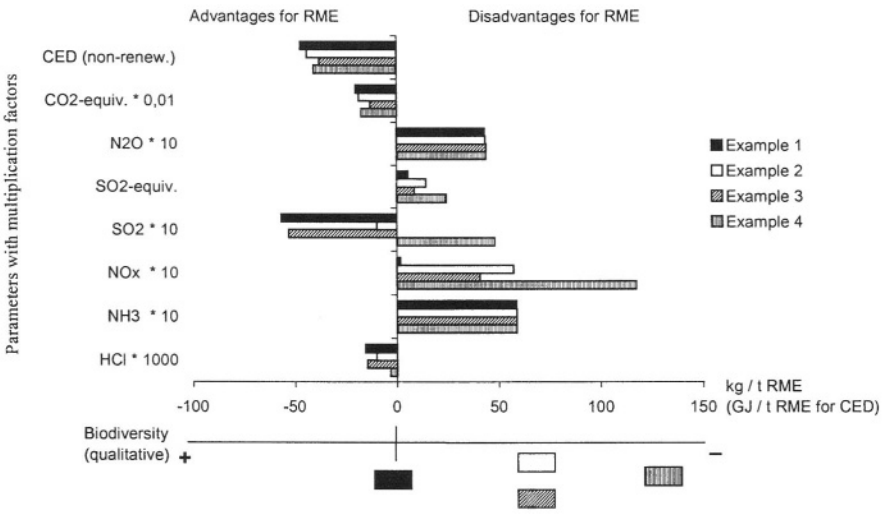

Figure 8.4. Results for four scenarios comparing RME versus conventional diesel fuel, using different reference systems (as shown in Figure 8.3). See Section 3 for the parameters displayed and for some important sources of the methodology and inventory data

For the calculations, complete life cycles were considered as explained in Section 1 (see Figure 8.1). Considering complete life cycles means accounting for all relevant by-products and their equivalent products (*i.e.* rape seed meal and soy cake or glycerine from rape seed oil and from mineral oil, *cf.* Figure 8.6). This is taken into account for all calculations made in this chapter. The calculations were done both for RME as well as

conventional diesel and a comparison was carried out based on those results. This whole procedure was then carried out four times, each time with a different reference system – as shown in Figure 8.3. Figure 8.4 indicates that the choice of the reference system can indeed have a significant effect on the overall results. The various parameters show very different patterns of differences between the four scenarios.

Thus for example NH_3 emissions are virtually unaffected by the reference system, whereas the NO_x emissions differ quite widely. Figure 8.5 indicates the reason for such differences: in this case, all environmental impacts due to transport were excluded from the calculations, *i.e.* only the agricultural production and processing were considered. In both cases biodiversity was only assessed qualitatively due to a lack of a generally accepted methodology regarding this parameter.

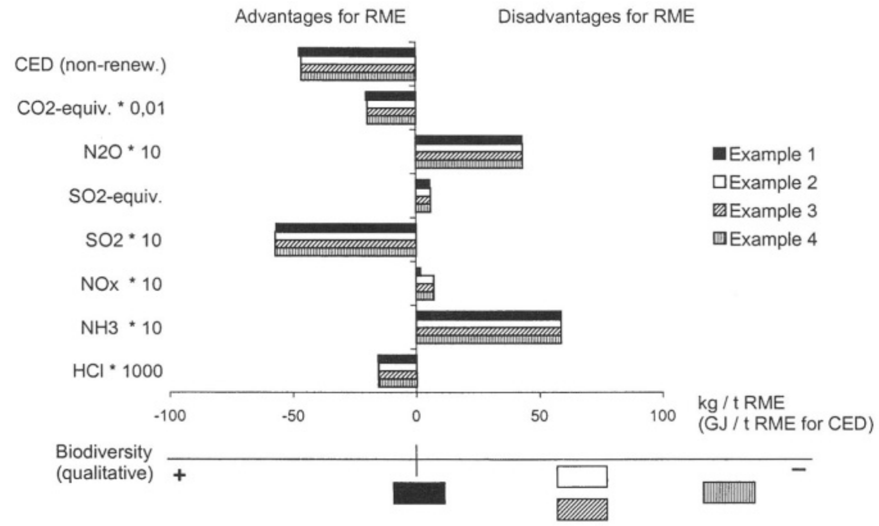

Figure 8.5. Results of four LCAs comparing RME versus conventional diesel fuel, using different reference systems but excluding transport impacts. See Section 3 for the parameters displayed and for some important sources of the methodology and inventory data

Again for instance the NH_3 emissions are equal for all four scenarios. Furthermore, they are also not different from the values shown in Figure 8.4, indicating that the NH_3 emissions are generated through agricultural processes. It is clear that the differences in the results caused by the reference system are almost entirely due to the transport of the various materials. The reason for this is as follows: in any chain of land use

changes as given in Figure 8.3, it was assumed that the environmental impacts of agricultural production of the same product are equal in all countries – an assumption that may be challenged but which will not influence the results significantly with regard to the quantitative parameters considered here. Therefore *e.g.* regarding maize production in Germany and France respectively (example 3), the effects 'cancel' each other out, since maize will be produced in both cases – either in Germany or in France. This effectively leaves the comparison of the production of the 'target product' (rape seed) versus fallow set-aside, natural fallow or rainforest. In the case of the latter two, the environmental impacts are considered to be zero, while for fallow set-aside there are certain effects due to fallow maintenance. These differences can be seen in Figure 8.5, revealing that they only reach a significant scale with regard to NO_x. NO_x is in fact the only quantifiable parameter where the reference area (fallow set-aside) has a noticable effect on the overall result due to significant emissions from fallow maintenance. Another parameter, though not yet quantifiable, which is influenced directly by the reference area in this case is biodiversity: the clearing of a rain forest area for rape seed production obviously has a greater impact with regard to this parameter than the cultivation of an area that would otherwise remain fallow set-aside land.

Thus, since firstly all chains of land use changes within an agricultural reference system must end with a non-productive land use, since secondly the effects of all other parts of the chain cancel each other out, and since finally the differences in the environmental effects between the production of an agricultural good and various forms of fallow land in this case are fairly similar with regard to the quantifiable parameters selected, it follows that the main effect of the reference system is not due to agriculture but to other processes such as transport.

Therefore it can be argued that if only the direct effects of land use are considered, in this case there is little difference in the results whether rape seed is produced on set-aside land or instead of maize. This difference only becomes significant if indirect effects such as transport etc. are also considered.

3.2 Different geographical boundaries

From the findings in Section 3.1 a further conclusion can be derived, which shall be explained by example 5: if for certain reasons (*e.g.* political or economic) the geographic boundary of the LCA is chosen to be limited to a certain country or region, *i.e.* if only the environmental impacts within this

boundary are considered, then many of the factors which give relevance to the reference system would not be included, such as transport processes taking place abroad. Figure 8.6 shows an example in which a limited geographical boundary was chosen for the comparison between RME and diesel.

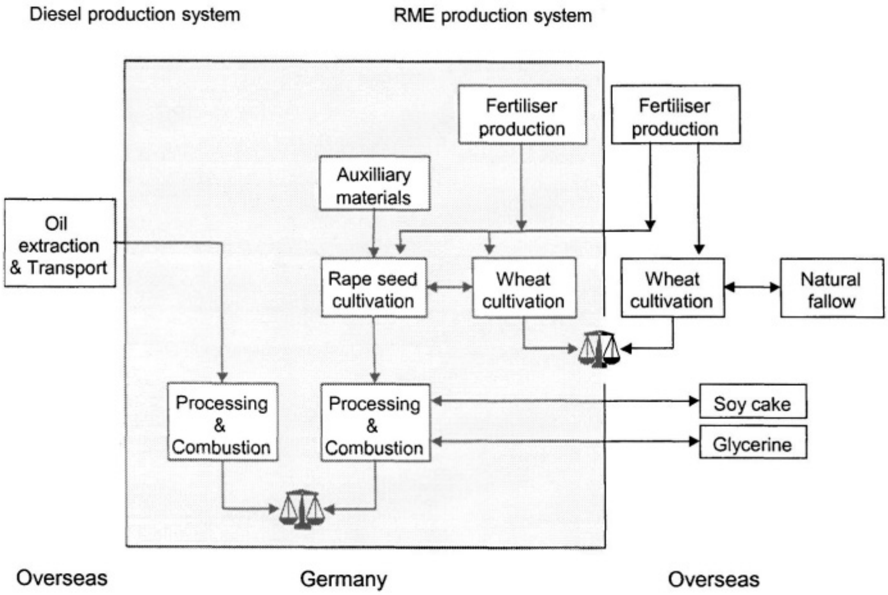

Figure 8.6. Example 5: life cycle comparison between RME and diesel with agricultural reference system under consideration of two different geographical boundaries

In this case, rape seed is cultivated in Germany instead of wheat, as in example 2 above. According to the requirements of an LCA all the elements shown here would have to be considered. If however only the geographical boundary of Germany would be considered, as represented by the shaded box, those parts of the production system which take place abroad would be ignored. This would lead to different results, as shown in Figure 8.7.

From this it becomes clear that considering only a limited geographical boundary rather than the global situation can lead to significantly different results. In example 5 for instance RME shows much greater advantages if the effects only arising within Germany are considered, mainly because of the impacts of wheat cultivation, which in the global scenario would be 'cancelled out' in the calculation due to wheat cultivation overseas.

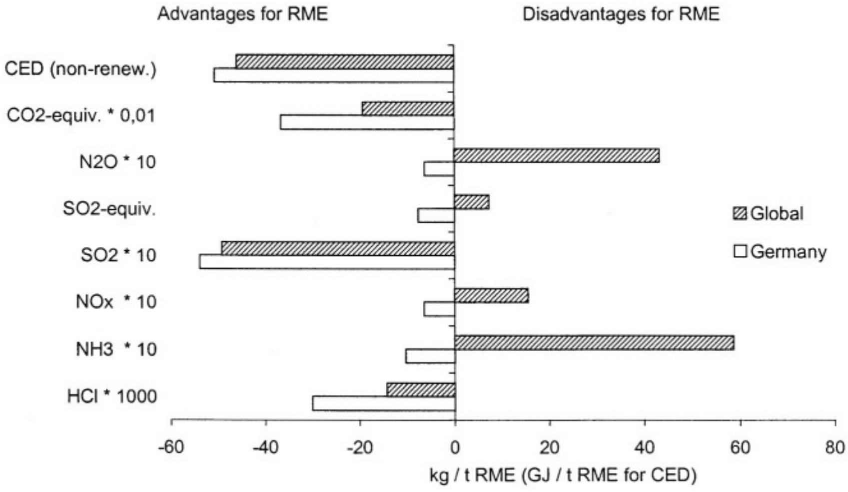

Figure 8.7. Results for example 5. See Section 3 for the parameters displayed and for some important sources of the methodology and inventory data

Thus in this case again it would make a difference whether the reference area would consist of fallow land or food production, because the latter would have greater repercussions on the global situation than the former.

As a result of such effects, arbitrarily choosing a non-global geographic boundary is not valid within a complete LCA considering all effects from cradle to grave – although it may be valuable within certain political or economic contexts.

3.3 Different combinations of land use producing the same utilities

Finally, a further example shall illustrate how different combinations of land use can be employed to produce the same commodities and yet generate very different environmental impacts: in the following examples three different systems are compared, where each system can be regarded as being the respective reference system for one of the others. The issue investigated is a comparison between the following three systems:

- conventional farming in combination with bioenergy (RME) production
- conventional farming in combination with fallow set-aside and conventional diesel
- organic farming in combination with conventional diesel fuel

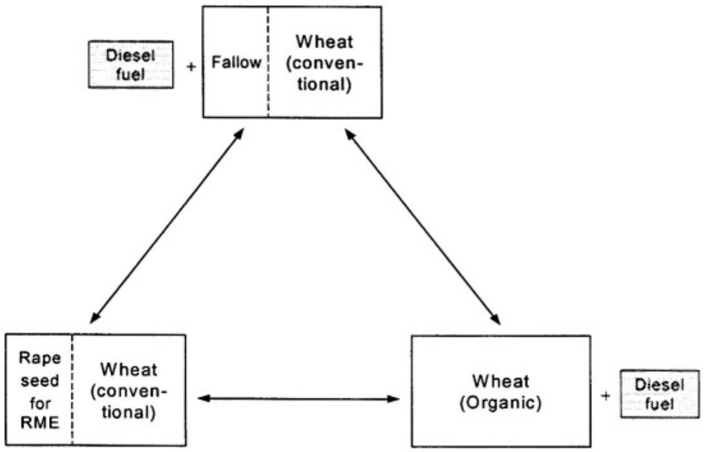

Figure 8.8. Three different systems producing equivalent commodities on the same amount of land, using different production methods

	System A	versus	System B
Example 6	Conventional wheat production + RME		Organic wheat production + Diesel
Example 7	Conventional wheat production + Diesel		Organic wheat production + Diesel
Example 8	Conventional wheat production + RME		Conventional wheat production + Diesel

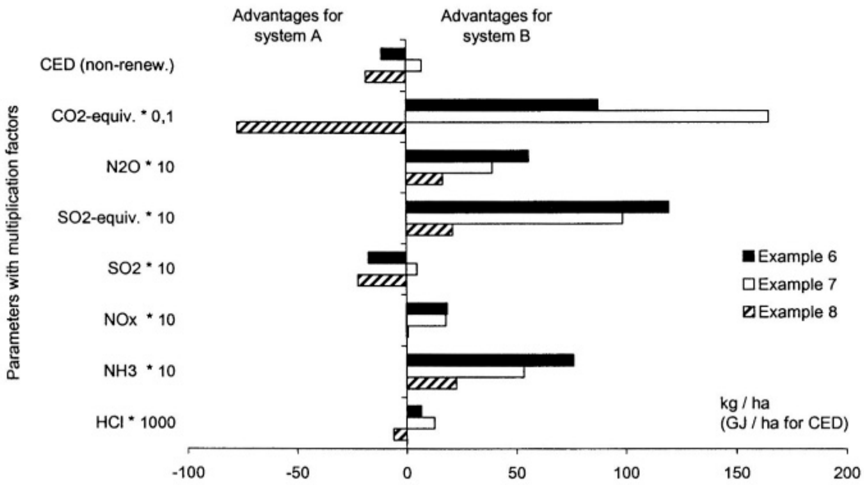

Figure 8.9. Comparison of three alternative systems combining different forms of land use and use of fossil resources. See Section 3 for the parameters displayed and for some important sources of the methodology and inventory data

In this example the same area size is considered in every system. However, since conventional farming methods tend to achieve higher yields than organic farming, the ‘surplus’ area can be used *e.g.* for biofuels – or for fallow. The comparison of the results shows that even when an equal area size is considered and the same commodities are produced, the results of the calculations may differ widely between the various systems, depending on the production methods and the way in which surplus land is utilised. Thus the examples presented here show once more how crucial it is to define the question to be answered by the LCA very precisely, and conversely, that the results must be discussed and interpreted only within the context and the particular conditions and system boundaries relevant to the individual case.

4. CONCLUSION AND OUTLOOK

The theoretical considerations as well as the examples presented above indicate that the precise definition of an appropriate reference system is of critical importance within agricultural life cycle analyses. The reference system comprises firstly the reference area which defines the environmental effects arising if the area in question was to be utilised differently, and secondly it includes any indirect effects that arise from the respective land use, for example additional transports or emissions due to different production methods, as well as the effects of potential land use changes elsewhere that result from the investigated production. As discussed in Section 2 it must finally end with an area that does not produce any economic commodity.

The examples shown here indicate that different agricultural reference systems lead to different scenarios which can have a significant impact on the results. In practice, the reference system is not ‘chosen’ or ‘derived’ but can be directly deduced from the question on which the LCA is based, provided that this question is formulated precisely enough. Therefore, it is an important aspect of any LCA to clearly define the question to be answered through it. This is also crucial to the question of how biofuels compare to conventional fossil fuels in environmental terms, under the respective conditions relevant to the particular case.

ACKNOWLEDGEMENTS

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Chapter 9

ENERGY FROM HEMP? ANALYSIS OF THE COMPETITIVENESS OF HEMP USING A GEOGRAPHICAL INFORMATION SYSTEM

Claus Brodersen, Klaus Drescher and Kevin McNamara[1]

1. INTRODUCTION

The objective of the study was to predict the competitiveness of regional hemp production in Germany based on economic and agronomic factors. Using these results in a second step, the competitiveness of hemp as a renewable energy source was determined. In order to reach these goals, a Geographic Information System (GIS) in combination with Linear Programming Models was used to obtain insights in (1) yield potentials of hemp, (2) potential cultivation locations, (3) minimum prices for hemp to be competitive, and (4) possible effects of an increasing hemp production on the EU budget.

Legalization of hemp production in Germany in the mid 1990s and the establishment of an accompanying subsidy program stimulated farmers' interest in hemp, especially since hemp subsidies were in contrast to other crop and animal support programs unchanged (BELF 1994). Throughout the agricultural community there has been interest in learning about all aspects of the hemp industry, from production to marketing at the commodity level to processing and uses at the product level. In response to this interest, the German Federal Ministry of Agriculture commissioned a feasibility study examining the potential for producing, processing and using hemp in Germany. This chapter is based on a study that analyzed potential locations and production levels for hemp in Germany. It discusses analysis to predict regional hemp production in Germany based on both economic and agronomic factors, as well as the competitiveness of hemp as a renewable energy source.

Hemp production was outlawed in Germany in 1981. Prior to that time production was limited (Filip 1997). Consequently, historical

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production data are not available. Our analysis, therefore, combined experimental station data with production data from other countries to predict the size and location of hemp production in Germany. Farm optimization models (LPs) constructed with a geographical information system (GIS) allowed the creation of sub-county agricultural land capabilities reflecting the area's productivity. Farm models constructed for each of these regions were used to evaluate hemp production's competitiveness, locally. The analysis determined both where hemp production would occur and the minimum price at which hemp production would be competitive on both set-aside and regular farmland. The analysis also evaluated federal fiscal impacts of various production scenarios.

The following section of the chapter describes data and the structure of the models used in analysis. Results related to competitiveness of hemp production in Germany are then presented. The final section discusses the competitiveness of hemp as an energy source.

2. OBJECTIVE, ANALYTICAL METHODS AND DATA

One objective of the study was to estimate potential hemp production locations and quantities. A Geographic Information System (GIS) model was used to construct land units for agricultural land throughout Germany. ARC-Info software was used in the analysis. ARC-Info allows data to be organized so that specific areas can be designated on the basis of either spatial attributes of the data or mathematical combinations of empirical parameters. ARC-Info processes all geometry forms (*e.g.* dots, lines, areas, and grids) that can be specified with relevant data parameters. Geometric data can be subdivided into grid and vector data which allow polygon overlay so there are no restrictions concerning the size of blended areas. This tool has been used to analyze specific agriculture issues since the mid 80s (Johnson 1993; Lex 1995; Liebhold and Elkinton 1988; Bill and Fritsch 1994).

GIS enabled the creation and classification of German agricultural land into units on the basis of agronomic, climatic, and economic attributes. A land unit was assigned to agricultural land on the basis of overlapping or common agronomic and climatic attributes. These units became the scale of observation for the hemp production analysis. Data profiles for each land parcel or area were used in linear programming models to estimate the spatial distribution and production levels of hemp in Germany under varying price assumptions.

Linear Programming Models (LPMs) were used to estimate hemp production levels for specific geographic areas, given the productivity of

their land and corresponding cost and structural data. The linear optimization approach is a mathematical planning tool based on linear relations that is frequently used for the determination of crop competitiveness (Rafsnider *et al.* 1993; Rae 1994). Koopmanns defined it as a method that optimizes total output by simultaneously considering competing production activities to find the solution that maximizes a dignified goal, given various restrictions and limitations (Steinhauser *et al.* 1992).

The general static linear optimization approach maximizes some objective function, *G,* considering production activities $(x_1, x_2, \ldots x_n)$, corresponding function values $(c_1, c_2, \ldots c_n)$, and limited resources $(b_1, b_2, \ldots b_n)$,

$$G_{max} = \sum_{j=1}^{n} c_j x_j$$

Production was constrained so that the sum of resources used across production activities did not exceed resource availability, or

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i$$

A non-negative condition on resource use was also imposed

$$x_j \leq 0$$

The optimization models required several assumptions about producers' objective functions and resource use. Our analysis assumed that farmers maximize profit. Also it assumed: production activities were linear (constant factor to product relation), inputs were divisible to any unit size, activities were additive and independent, all production occurred in the same period, production capacities were constant, no dis-investment or saving occurred, farms remained solvent, and production was guaranteed (Kruschwitz 1995; Brandes and Woerman 1982; Steinhauser *et al.* 1992; Hillier and Liebermann 1998).

The basic farm model used in the analysis was a farm with 40 ha of arable land with an addition of up to 10 ha rented. Annual farm household labor availability was 800 hours for crop activities with seasonal limitations (max 200 hours per season[2]). Additional labor could be hired at 20 DM per hour. Several other constraints—for example, regarding crop rotation of hemp (≤ 33%) and other crops (between ≤ 33% and ≤ 75%)—were made. Quotas and processing capacities limited the cultivated area of sugar beets and potatoes. Animal production was not considered. The objective of the farmer was to maximize the total net returns.

Data requirements of the analysis included yields, commodity prices, production costs and subsidy payments for hemp and primary

commodities by region. Additionally, soils data, climatic data, and county boundaries were incorporated into the analysis. Regional production and input price data for the primary commodities produced in each county were obtained from the Chamber of Agriculture Schleswig-Holstein (1995) and farm enterprise data from the Institute of Farm Management, University of Kiel (1995/96).

There are no historical hemp production or input data. Therefore, we estimated hemp production yields and costs from experimental farm budget data, hemp test plots data and from Belgium and France production data (Christen and Schulze 1997; Schulze 1995). Table 9.1 shows selected input and yield data for hemp under different product use assumptions.

Data on the aggregate size, structure and enterprise mix of farmland by county were obtained from KTBL-Taschenbuch data (1994/95); the Chamber of Agriculture, Schleswig-Holstein (1995), and the Institute of Farm Management, University of Kiel (1995 and 1996). Soil data were based on a soils map from the German Soil Association (Brodersen and Drescher 1997). Heat/temperature, precipitation, and frost data were mapped from data of the German Weather Service (Brodersen and Drescher 1997). Data to map county boundaries were obtained from the Institut of Angewandte Geodäsie (Brodersen and Drescher 1997).

3. MODEL CONSTRUCTION

Prediction of the location and level of hemp production at various price levels required estimation of the net returns from production of both hemp and commodities that would be profitable in each production area based on agronomic and economic attributes that influence productivity and cost of production. Procedures for estimating hemp's competitiveness are summarized in Figure 9.1. The first step was the construction of land classes based on agronomic and climatic attributes. GIS analysis was used to isolate land classes on the basis of soil type, rainfall, frost-free days, and geographic-group units. Each area, a sub-county unit, had common soil and climatic attributes. GIS county data were used to estimate yields for the nine most important crops—winter wheat, winter barley, spring barley, winter rye, rape seed (canola), oats, sugar beets, corn, and potatoes—grown in each county. County level land use and crop shares were also integrated into the model to be used in the production analysis. Crop yield attributes were then attached to each specific sub-county unit.

Initially, 10,004 different types or land classes were generated. Cluster analysis, focusing on commodity yields, was used to aggregate the initial areas into 25 land units reflecting different productivity types, as well as, production shares for its primary commodities.

Table 9.1. Hemp production input and yield data by product use (source: Brodersen and Drescher 1997)

	Structure	hemp fibre/straw			hemp seeds			hemp fibre/straw/seeds		
		yield ha^{-1}	DM $unit^{-1}$	DM ha^{-1}	yield ha^{-1}	DM $unit^{-1}$	DM ha^{-1}	yield ha^{-1}	DM $unit^{-1}$	DM ha^{-1}
OUTPUT	- seeds (100 kg)				10	35	350	8	35	280
	- straw (100 kg)	80	12	960				60	12	720
	- bonus (ha)			1510			1510			1510
	Total			2470			1860			2510
COSTS (variable)	- seeds (kg)	80	3.50	280	45	3.50	158	65	3.50	228
	- fertilizer (kg)									
	N	100	1.00	100	100	1.00	100	100	1.00	100
	P_2O_2	85	0.65	55	85	0.65	55	85	0.65	55
	K_2O	120	0.50	60	120	0.50	60	120	0.50	60
	- insecticides etc.	-	-	-	-	-	-	-	-	-
	- drying costs	-	-	-	10	2.70	27	8	2.70	22
	- machinery costs (own)			210			270			210
	- machinery costs (other)			600			300			800
	- transport costs			207			20			207
	- storage costs			60			-			40
	- interest (8%)			25			25			25
	Total			1597			1015			1747
	VAR. GROSS PROFIT			873			845			763
	FACTOR CLAIMS									
	- farmland (ha)	1.0			1.0			1.0		
	- preceding crop (ha)	1.0			1.0			1.0		
	LABOR NEED HOURS									
	- spring (early)	1.2			1.2			1.2		
	- spring (late)	-			-			-		
	- summer	2.5			2.5			2.5		
	- autumn	4.5			4.5			4.5		
	- Total	8.2			8.2			8.2		

After physical crop yields were established for each of the 25 land units in each county, 400 commodity price maps were overlaid. These maps included both actual market prices and production subsidies. German agriculture is supported by a variety of commodity support programs that subsidize producers for production of specific commodities on the basis of the commodity's competitiveness with other regions. The subsidy program is a key determinant of what commodities are produced across Germany because of their influence on net returns. Therefore, subsidy data maps were overlaid on a map with the initial 25 land units to create land classes that incorporated the influence of subsidies. The result was an expansion of the initial 25 land units to 126 units.

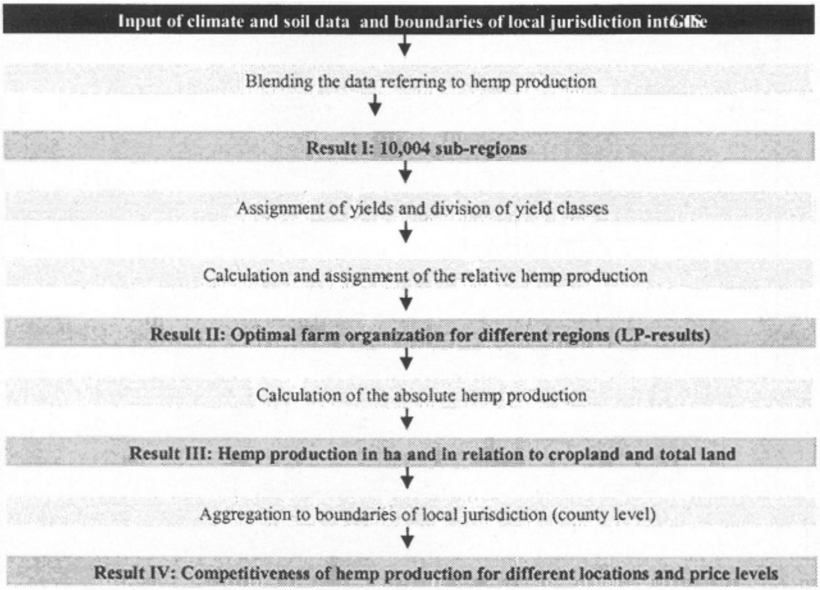

Figure 9.1. Procedure to determine the competitiveness of hemp production in different regions and for different price levels

Vector oriented GIS was then used in conjunction with Linear Programming Models (LPMs) to estimate yield for hemp production. LPMs for each production area's primary commodities were also estimated so that hemp's competitiveness could be estimated. The analysis required that input/price data for hemp and alternative crops conform with the 126 land units to estimate both physical yield and production value of hemp as well as rival commodities in each production area. These production models provide the basis for examining hemp's competitiveness with other locally produced crops at various hemp yield and price levels. This analysis

was the basis of the determination of the competitiveness of hemp production in each land unit.

The 126 land units did not correspond to any political boundaries. Counties had several different land units. Consequently, the prorated area of each region was set as the ratio of cropland (UAA) to total land to determine the competitiveness of hemp production.

Initial model estimates were run without hemp production as a potential activity to assess how well the LPM solutions compared with actual production. The estimated results showed a relative good fit with actual production shares, especially in the northern and eastern regions of Germany. The estimates for southern Germany were less accurate, perhaps because of the small-scale structure of agriculture in the south and the relatively large share of production by part-time or hobby farmers. In general, the more homogenous a county's soil and weather conditions, the better the fit between estimated and actual production.

The second series of models were estimated incorporating hemp production as a potential activity. Six hemp yields were considered in the analysis. As actual production data were not available, the yield estimates were based on agronomic research data and production data (Christen and Schulze 1997). A left skewed distribution with an average 8 tons per ha yield of hemp straw was assumed. Yield values used in the estimated models were 8 tons per ha with reductions of -25%, -12.5% -7.5%, and increases of +5%, and +10% from the median of 8 tons.

A total of 756 model variants were calculated[3]. These calculations, combined with the GIS results, allowed us to estimate the competitiveness of hemp in each county, as well as the level of hemp cultivation. Hemp production was considered for both non set-a-side land (regular land) and set-a-side land. Hemp production never occurred on set-a-side plots in the optimal solution because of lower hemp subsidies for these plots.

LPMs were also calculated for all 126 land units to determine the minimum hemp price required for hemp to enter farm models as a production activity on unrestricted farmland and on set-aside land. A total of 6048 LPMs were estimated, one for each of the 6 yield levels with 8 price levels varying between 13 DM/100 kg to 5 DM/100 kg for each of the 126 regions (126 regions * 6 yield levels * 8 prices). The results of these model runs can be displayed on maps to visualize the variation in geographic dispersion and quantity of hemp produced under each yield and price assumption. To illustrate, Figure 9.2 shows the density of hemp production in relationship to total cropland at a price of 6 DM/100 kg and Figure 9.3 shows the density at a price of 12 DM/100 kg. Because the share of cropland varies across counties—in some regions in East Germany the

share of cropland is relatively small—Figures 9.4 and 9.5 show density in relation to total area at different prices (6 and 12 DM per 100 kg/straw).

It was assumed that the government paid a subsidy of 1,510 DM for each planted hectare of hemp. As total hemp production increases, it can be assumed that the subsidy levels would decline. Consequently, a fourth set of production models was calculated to determine how much the price of hemp straw would have to increase to compensate for reduced subsidy payments.

4. RESULTS

The primary results of our model analysis of competitiveness of hemp production for on regular land are visualized in Figure 9.2 to 9.5 and listed below.

- Under current economic and political conditions, hemp production was competitive with a 1,510 DM subsidy and a straw price of 12 DM/100 kg (Figure 9.3). In most counties hemp production entered the optimal solution as a production activity (112 out of 126 models) at a production level equal to the 33% rotational limit. When the straw price was lowered to 9 DM/100 kg, hemp production entered as an activity in the optimal production solution for most counties.
- If monoculture of hemp is assumed—including slightly higher pesticide costs and no yield depression—hemp production accounts for up to 70% of the total areas. Only potatoes, wheat and sugar beets can compete.
- The only counties in which hemp production did not enter the optimal production solution were those with high grain and canola yields and subsidies. Generally, hemp production did not enter the solution for counties in Holstein and NRW.
- The threshold price at which hemp entered as a production activity varied from 5.04 DM/100 kg hemp straw in Barnim county (Brandenburg) to 13.44 DM/100 kg hemp straw in Holstein and NRW.
- Reduction or elimination of government production subsidies would require hemp processors to pay farmers considerably higher prices to maintain production. A hemp price of 24 DM/100 kg straw would be required for hemp production to enter the optimal solution in Barnim county (Brandenburg).
- The competitiveness of hemp as a production activity varied from north to south and from west to east. Hemp production was most competitive in Eastern and Southern Germany. In the West and North it only entered the optimal solution at a crop yield of 8.8 tons straw/ha

and a price of 13 DM 100 kg/straw. Note that both of these values are at the high end of the hemp production ranges considered in the analysis.

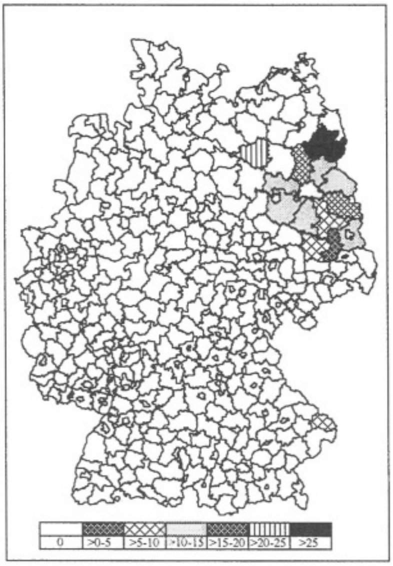

Figure 9.2. Cultivation density of hemp in relation to cropland at a revenue of 6 DM per 100 kg/straw

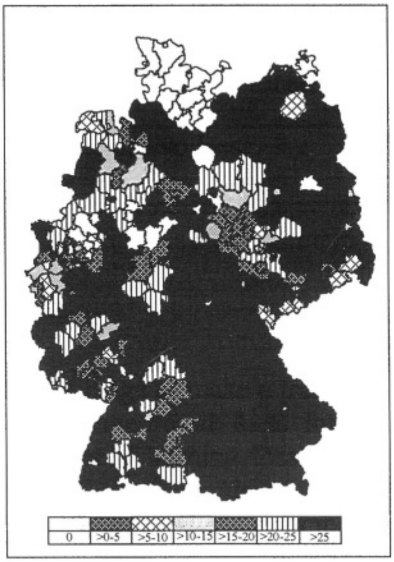

Figure 9.3. Cultivation density of hemp in relation to cropland at a revenue of 12 DM per 100 kg/straw

Figure 9.4. Cultivation density of hemp in relation to total area at a revenue of 6 DM per 100 kg/straw

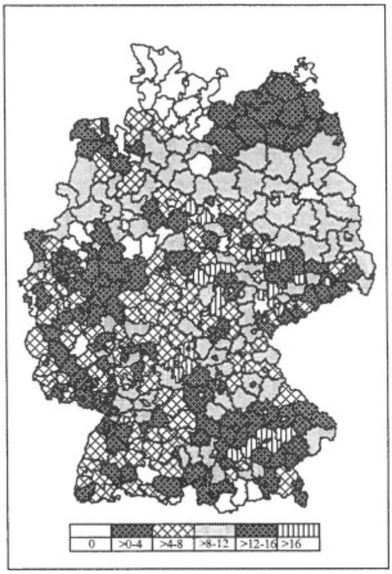

Figure 9.5. Cultivation density of hemp in relation to total area at a revenue of 12 DM per 100 kg/straw

Hemp production would become the primary commodity produced in Germany if output (straw) markets were fully operational, seed was readily available, average yield was 8 tons and the price received was 12 DM 100 kg/straw plus a subsidy of 1500 DM per hectare. A corresponding burden on the EC budget would go along with that development.

Additionally, our results suggest that cereal production (and, more specifically, less profitable and lower-yield crops like oats and rye) would be displaced by hemp given the current subsidies. Thus, we can estimate the additional expenses the EC would face in relation to the varying cultivated area. The additional subsidy required price, can be calculated by multiplying the area used for hemp production by the hemp premium, subtracting the area used for grain production multiplied with the regional subsidy level for grain. These hypothetical calculations lead to the following results:

- The additional budget expenses, when expanding the cultivated area of hemp, show a restrained increase within the bounds of 5 DM per 100 kg /straw to 8 DM per 100 kg/straw. Expenses increase by almost 400 Mill. DM at a price of 8 DM per 100 kg/straw (see Figure 9.6). Hemp cultivation tends to be increasingly included in the optimal production plan above a hemp straw price of 9 DM per 100 kg/straw causing the expenditure curve to have an almost exponential form and the additional budget expenses to rise up to 2.9 Bill. DM (Figure 9.6).

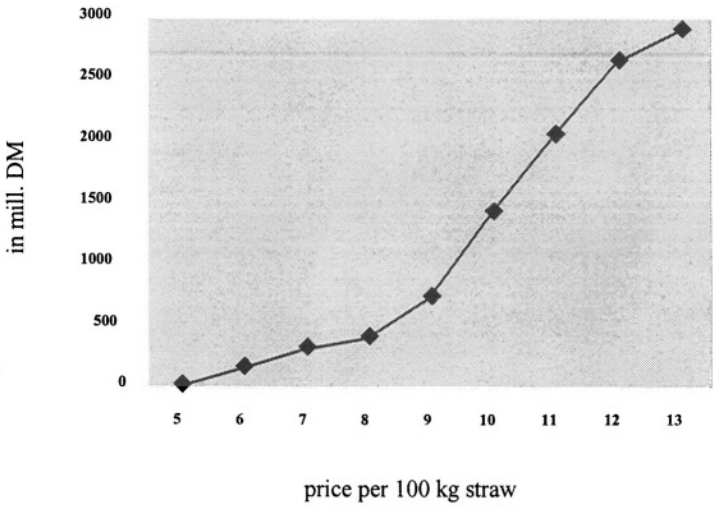

Figure 9.6. Budget expenses (subsidies) at varying hemp straw prices (in Mio. DM)

- A possible consequence of high subsidies, which should not be underestimated, is their abuse (this is not an allegation that farmers have deceitful intentions).
- The additional budget expenses, shown in Figure 9.6, consider only theoretical expansion of hemp production in Germany. Corresponding increases would occur in the other EC countries.
- Besides the burdens named already, additional negative effects on the budget should be expected; for example, additional administrative expenses for controlling the hemp cultivation area and hemp harvest.

5. HEMP AS ENERGY SOURCE

Hemp is one of the oldest cultivated crops and has a variety of uses, including use of the whole plant as an energy source. After a first dew rotting process, hemp straw consists of 31% bast fiber, 52% shives, 8% seed, and 9% other substances. The most valuable raw material is bast fiber. Consequently, using hemp as an energy source should be connected with the exploitation of the shives, after the bast fiber is extracted from the stems.

Use of these shives for energy production would require hemp production to be located close to the energy plants due to the low value density of the raw commodity and corresponding high transportation costs. For example, 100 kg of un-pressed shives occupies more than one cubic meter. Compressing the raw material to reduce transport cost is technically feasible. However, investment for a briquette production process is not economically viable at current energy prices (Wolpers 1986).

Given transportation costs, the optimal location of an energy plant should be evaluated on a local and regional level rather than a national and international level. Because hemp is characterized by a quick decreasing transportation worth, the agricultural conditions and locations mainly determine the location of the power generation. It follows that energy from hemp—if it will be an alternative to conventional generated energy—can only be competitive in rural areas with production sufficient to fuel a power plant.

The most competitive locations in Germany are counties in the state Brandenburg. Hemp production in these counties even occurs if the subsidy payments by the EC will dramatically decrease or the processing stage pays less than 10 to 12 DM per 100 kg/straw.

Energy plants should be located near cities and smaller towns for an efficient use of the district heating. Lower land prices favor locations in

former East Germany. Locations in the five new states are also more competitive due to lower wages and construction costs.

Due to high transportation costs, relatively low land prices and low construction costs, locations in the rural areas of the five new states are most competitive for power and heating stations. However, the basic question, if generating energy from hemp is efficient at all, has not yet been answered.

There are methods for using hemp as an energy source. Hemp can be used exclusively to generate energy or in a two stage process. First, the bast fibres are extracted from the stem and then the rest of the plant can be used as a waste product for generating heat or electricity. But the value of the shives is mainly determined by alternative energy sources. Comparing hemp with fossil fuels must consider the capital and transportation costs as well as commodity price. Comparing hemp with other renewable energy sources, the commitment costs of hemp have to be compared with the commitment costs of the most favorable alternative energy source.

Table 9.2: Value of wood chips and derived value of hemp shives

Sources of the wood chips	Cost per ton dry mass (inclusive transport costs)	Price hemp shives should not exceed to be competitive with ... (energy density per ton dry weight [factor 17/18.5)
Industry residue	33.1	30.4
Horticulture residue	57.1	52.5
Forest residue	112.9	103.7
Plantation production	200.9	184.6

Source: Wintzer *et al.* (1994) and Böcker (1997)

Currently, the production of hemp bast fiber is not competitive with alternative fiber production at a volume exceeding the demand of a small niche market (Böcker, 1997; Gorn and Schumacher, 1997). A niche market volume for bast fiber does not meet the requirements necessary in the case of using hemp as an energy source. Consequently, only the sole use of hemp for generating energy is possible.

This process mainly competes with wood chips, a product which has similar characteristics with regard to the burning process. Table 9.2 shows that hemp cannot compete with wood chips. Hemp production starts, despite high subsidies, by about 70-80 DM per ton hemp straw, assuming a yield of 8 tons per hectare. Converting this quantity to dry weight and adding transportation costs leads to a cost of probably 200 DM per ton. Thus, the competitiveness of hemp is comparable with fast growing plantations (for example polars) which itself cannot compete with oil and gas at current prices. Therefore, it is not expected that the cultivation of hemp for energy production have a future in Germany.

6. SUMMARY AND CONCLUSIONS

Our research analyzed the competitiveness of hemp production and estimated the potential cultivation locations. The analysis used a Geographic Information System (GIS) in combination with Linear Programming Models to estimate (1) quality and yield potentials of hemp and alternative products, (2) potential cultivation locations, (3) minimum prices for hemp to be competitive for different conditions and locations, and (4) possible effects of hemp production on the EU budget. Due to relatively high transport and raw material costs, hemp cultivation is not suitable for energy production.

NOTES

[1]Authorship is equally shared.
[2]The season/growth period is divided into (a) spring [early], (b) spring [late], (c) summer, and (d) autumn.
[3]126 land units times 6 yield classes is equal to 756 models.

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Chapter 10

THE ROLE OF FORESTRY IN CLIMATE CHANGE AND SUSTAINABLE ENERGY PRODUCTION

G. Cornelis van Kooten, Emina Krcmar and Peter J. Graham

1. INTRODUCTION

Managing forests solely for their commercial timber values leads to market failure because too much forestland is harvested relative to what society desires, or it is harvested in ways that are considered detrimental to other forest values. Market failure occurs because markets do not adequately capture the benefits associated with the environmental amenities that forests provide, so that the level of provision of those amenities is below what is economically optimal. A major environmental amenity pertains to climate change.

Forests are an important terrestrial carbon (C) sink, which generally store more C at a faster rate (during forest growth) than other terrestrial sinks. Forests store C by photosynthesis, with each m^3 of wood storing approximately 200 kg of C. For every tonne (t) of C sequestered in forest biomass, 3.667 t of CO_2 is removed from the atmosphere. Countries that have a large forest sector are interested in C credits related to forest management and reforestation, and those with large tracts of (marginal) agricultural land are interested in afforestation as a means of achieving some of their internationally agreed upon CO_2-emissions reduction. Further benefits are possible if account is taken of wood product sinks (*e.g.,* construction lumber, paper in landfills) or wood biomass used to produce energy in place of fossil fuels. These topics are the foci of this paper.

We begin in the next section by considering the role of forestry, land use change and land management as methods for sequestering carbon, and discuss the function of reforestation and afforestation in the mitigation policy arsenal. Since trees do not grow indefinitely, it is important to consider what to do with them at maturity. While simply leaving them as a

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permanent C sink is one option, it is better to harvest and replant the sites, either sequestering C in wood products or reducing CO_2 emissions from fossil fuels by generating energy from wood biomass instead. We consider the latter option because studies indicate that, if trees are harvested for pulp and other wood products, stumpage prices will fall, thus leading owners to convert forestland to other uses. Land use issues related to biomass burning are examined further in section 3. Finally, in section 4, we consider economic instruments and institutions (regulation and markets) for enhancing forestry's part in mitigating climate change. The conclusions ensue.

2. FORESTRY'S CONTRIBUTION TO CLIMATE CHANGE: LAND USE CHANGE

At the third Conference of the Parties (COP) to the 1992 UN Framework Convention on Climate Change at Kyoto, December 11, 1997, industrialized countries agreed to reduce their CO_2 emissions by an average 5.2% from the 1990 level by 2008-2012. Article 3.3 of the Kyoto Protocol permits countries to store carbon in forest sinks in lieu of reducing CO_2 emissions; reforestation and afforestation can provide carbon credits (deforestation results in a debit), while burning of wood biomass for energy in place of fossil fuels reduces CO_2 emissions. Article 3.4 leaves to negotiation the role of other carbon (C) sinks, such as wood product, soil and wetland sinks. As a result, policy makers and researchers are interested in the potential role of terrestrial sinks in mitigating climate change, and in institutions and economic incentives that treat certified carbon credits (or emission offsets) in the same way as actual CO_2 emissions reduction. Thus, countries with a significant landmass hope to use domestic forestry projects to achieve a significant component of their Kyoto target. Canada, for example, envisions meeting 22% of its Kyoto commitment through terrestrial sinks (Canadian Pulp & Paper Association 2000).

Carbon credits can also be obtained for activities in developing countries and economies in transition. Kyoto's Clean Development Mechanism (CDM) enables industrialized countries to purchase certified offsets from developing countries by sponsoring projects that reduce CO_2 emissions below business-as-usual levels in those countries. Likewise, emission reduction units can be produced through Joint Implementation (JI) projects in countries whose economies are in transition. Projects that prevent or delay deforestation and land-use change, or result in the establishment of plantation forests, are eligible under the CDM and JI.

Collectively the terrestrial carbon sink projects described above are referred to as land use change and forestry (LUCF) projects. What is

strange about the Kyoto Protocol is that the 1990 baseline for greenhouse gas emissions does not include terrestrial C flux, but the calculations for determining compliance for 2008-2012 do. Baseline emissions are founded on gross emissions, while compliance is based on net emissions. A country could conceivably meet its emissions reduction target even though its gross emissions have increased. It can do this, say, through domestic LUCF projects and/or foreign ones under the CDM or through JI.

The role of terrestrial sinks and whether market mechanisms should treat carbon offsets the same as emissions reduction are a source of dispute. An attempt to reach an agreement on these and other outstanding Kyoto issues was made at the sixth COP in The Hague, Netherlands, during November 2000. COP6 failed partly because European countries took the view that there should be limits to the role of sinks and LUCF projects so that countries would be forced to address emissions reduction. Europeans fear that LUCF projects are ephemeral and do not help to reduce the long-term, upward trend in CO_2 emissions. The opposite view is that CO_2 emissions reduction and carbon sinks are no different in their impact and should be treated the same on efficiency grounds (Chomitz 2000).

In principle, a country should get credit only for sequestration above and beyond what occurs in the absence of C-uptake incentives, a condition known as “additionality” (Chomitz 2000). Thus, for example, if it can be demonstrated that a forest would be harvested and converted to another use in the absence of specific policy (say, subsidies) to prevent this from happening, the additionality condition is met. Carbon sequestered as a result of incremental forest management activities (*e.g.,* juvenile spacing, commercial thinning, fire control, fertilization) would be eligible for C credits, but only if the activities would not otherwise have been undertaken (say, to provide higher returns or maintain market share). Similarly, afforestation projects are additional if they provide environmental benefits (*e.g.,* regulation of water flow and quality, wildlife habitat) not captured by the landowner and would not be undertaken in the absence of economic incentives, such as subsidy payments or an ability to sell carbon credits (Chomitz 2000). Which LUCF projects meet the requirements for additionality?

2.1 Land use change

Consider first the role of tropical deforestation.[1] Tropical forests generally contain anywhere from 100 to 400 m^3 of timber per ha, although much of it may not be commercially useful. This implies that they store some 20-80

tonnes of C per ha in wood biomass, but this ignores other biomass and soil C. An indication of total C stored in biomass for various tropical forest types and regions is provided in Table 10.1. The C sink function of soils in tropical regions is even more variable across tropical ecosystems (see Table 10.2, col. 2). This makes it difficult to make broad statements about carbon loss resulting from tropical deforestation. Certainly, there is a loss in C stored in biomass (which varies from 27 to 187 t C ha^{-1}). There may or may not be a significant loss in soil C depending on the new land use (agricultural activity) and the tropical zone. While conversion of forests to arable agriculture will lead to a loss of some 20-50% of soil C within 10 years, conversion to pasture may in fact increase soil C, at least in the humid tropics (see Table 10.2). One thing is clear, conversion of forestland to agriculture leads to a smaller carbon sink, with a greater proportion of the ecosystem's C stored in soils as opposed to biomass (Table 10.3). To address this market failure (release of C through deforestation), policies need to focus on protection of tropical forests.

Table 10.1. Carbon content of biomass, various tropical forests and regions

Country/Forest	Wet Tropical	Dry Tropical
Africa	187 t C ha^{-1}	63 t C ha^{-1}
Asia	160 t C ha^{-1}	27 t C ha^{-1}
Latin America	155 t C ha^{-1}	27 t C ha^{-1}

Source: Papadopol (2000)

Table 10.2. Depletion of soil carbon following tropical forest conversion to agriculture

Tropical Region	Soil Carbon in Forest	New Land Use	Loss of Soil Carbon with New Land Use
Semi-arid	15-25 t C ha^{-1}	Shifting cultivation (arable agriculture)	30-50% loss within 6 years
Subhumid	40-65 t C ha^{-1}	Continuous cropping	19-33% loss in 5-10 years
Humid	60-165 t C ha^{-1}	Shifting cultivation	40% loss within 5 years
		Pasture	60-140% of initial soil C

Source: adapted from Paustian *et al.* (1997)

Table 10.3. Total carbon in tropical ecosystems by sink, percent[a]

Land Use	Tree	Understorey	Litter	Root	Soil
Original Forest	**72**	**1**	**1**	**6**	**21**
Managed & logged over-forest	72	2	1	4	21
Slash & burn croplands	3	7	16	3	71
Bush fallow	11	9	4	9	67
Tree fallow	42	1	2	10	44
Secondary forest	57	1	2	8	32
Pasture	<1	9	2	7	82
Agroforestry & tree plantations	49	6	2	7	36

[a] Average of Brazil, Indonesia and Peru.
Source: Woomer *et al.* (1999)

It may be difficult, however, to prevent tropical deforestation from occurring. While mechanistic causes of land use change (logging, road construction, illegal land clearing by peasants, etc.) are often easy to identify, as are possible domestic policies for correcting these forms of market failure, the underlying or ultimate factor is government policy related to revenue and foreign exchange needs, and urbanization and population control (Bromley 1999). Income and/or the foreign exchange generated from logging concessions (*e.g.,* SE Asia) or the new land use (cattle ranching in Brazil) are important for some governments in tropical regions. Governments may also permit or even encourage land use changes as part of an overall policy to address urbanization pressure and general over-population in certain areas. Indonesia has moved peasants into outlying forested regions as a means of addressing over-crowding in Java, for example, while Brazil has promoted development of the Amazon in order to encourage migration into the region and away from more urbanized areas to the South.

Next, consider the role of land use change more broadly. Conversion of pasture into cropland will release carbon stored in the soil, while draining wetlands releases methane (CH_4). Changes in management practices will also cause C to be released or stored. An indication of the effect on terrestrial C sinks of enhanced management of existing land uses and changes in land use is provided in Table 10.4. This table gives estimates of the potential of these activities for mitigating climate change (i.e., the potential of land use management to achieve Kyoto targets). But it also demonstrates how current land uses have resulted in the release of C over time – for example, cultivation alone has resulted in the historical release of 54 Gt C (Paustian *et al.* 1997). While a strategy to reduce forest degradation (*viz.,* deforestation) is addressed in Table 10.4, reforestation and afforestation programs are ignored. These are considered in the next sub-section.

2.2 Enhanced management of existing forests and afforestation in northern countries

There remains disagreement about what is meant by reforestation and afforestation; some countries interpret reforestation to mean that any growth in trees planted on forestland denuded after 1990 is eligible for carbon credits. In effect, they want C credits for replanting forests that have been logged, thereby violating additionality. The Intergovernmental Panel on Climate Change (IPCC 2000) interprets reforestation as tree planting on land that had at some time in the past been in forest, but has recently been

in agriculture; Canada and some other countries interpret this as afforestation. According to the IPCC, afforestation refers to tree planting on lands that have never been and would not naturally be in forest. These disparate views are rooted in Kyoto's failure to take proper account of carbon in wood products. Canada and other major wood product exporters feel that their definition of reforestation simply recognizes the fact that much of the C in harvested timber gets exported and that the debit from logging should be therefore be charged to the importing country.

Table 10.4. Effects on potential net carbon storage of land use activities, excluding afforestation and reforestation [a]

Activity	Potential Area (10^6 ha)	Rate of C Gain (t C ha^{-1} yr^{-1})	Potential (Mt C yr^{-1}) 2010	2040
1. Improved management within a land use				
Cropland (reduced tillage, improved management of crop rotations, cover crops, etc.)	1,289 (45.7%)	0.34	125 (60%)	258 (51%)
Rice paddies (better irrigation, improved residue management)	153 (2.6%)	0.10	8 (<10%)	13 (<7%)
Agroforestry (better management of trees on cropland)	400 (20.8%)	0.28	26 (46%)	45 (38%)
Grazing land (better management)	3,401 (38.1%)	0.77	261 (36%)	523 (36%)
Forestland (enhanced silviculture, reduced degradation)	4,051 (46.9%)	0.41	170 (59%)	703 (72%)
Urban land (tree planting, improved wood product management & waste management)	100 (50%)	0.30	2 (50%)	4 (50%)
2. Land use change				
Agroforestry (conversion of poor crop/grassland to agroforestry)	630 (0%)	3.1	391 (0%)	586 (0%)
Restoring severely degraded land (to forest, crop or grass land)	277 (4.3%)	0.25	4 (<20%)	8 (13%)
Grassland (converting cropland to grassland)	1,457 (41.3%)	0.80	38 (63%)	82 (59%)
Wetland restoration (converting drained land back to wetland)	230 (91.3%)	0.40	4 (100%)	14 (93%)
GLOBAL TOTAL			**1,027 (39%)**	**2,235 (44%)**

[a] Contribution by developed countries provided in parentheses.
Source: IPCC (2000)

Reforestation needs to take into account the C debit from harvesting trees, but it also needs to take into account C stored in wood

product sinks (and exported C) and additional C sequestered as a result of forest management activities (*e.g.,* juvenile spacing, commercial thinning and fire control). Even when all of the C fluxes are appropriately taken into account, it is unlikely that 'additional' forest management will be a cost-effective and competitive means for sequestering carbon (Caspersen *et al.* 2000).[2]

Evidence from Canada, for example, indicates that reforestation does not pay even when C uptake benefits are taken into account, mainly because northern forests tend to be marginal (van Kooten *et al.* 1993). The reason is that such forests generally regenerate naturally, and returns to artificial regeneration accrue in the distant future. Only if short-rotation, hybrid poplar plantations replace logged or otherwise denuded forests might forest management be a competitive alternative to other methods of removing CO_2 from the atmosphere. Hybrid poplar plantations may also be the only cost-effective, competitive alternative when marginal agricultural land is afforested (van Kooten *et al.* 1999).

Surprisingly, despite the size of their forests and, in some cases, large areas of marginal agricultural land, there remains only limited room for forest sector policies in the major wood producing countries (Canada, Finland, Sweden and Russia). We illustrate this using the TECAB model for northeastern British Columbia (Stennes 2000; Krcmar and van Kooten 2001). The model consists of tree-growth, agricultural activities and land-allocation components, and is used to examine the costs of C uptake in the grain belt-boreal forest transition zone of BC. These estimates, extended to similar regions, provide a good indication of the costs of an afforestation-reforestation strategy for C uptake for Canada as a whole, and likely for other boreal regions as well. The study region consists of 1.2 million ha, of which nearly 10.5% constitute marginal agricultural land, with the remainder being boreal forest. The boreal forest is composed of spruce, pine and aspen.

For environmental reasons and to comply with BC's Forest Practices Code, the area planted to hybrid poplar in the model is limited only to logged stands of aspen and marginal agricultural land. Other harvested stands are replanted to native species or left to regenerate on their own, depending on what is economically optimal. Carbon fluxes associated with forest management, wood product sinks and so on are all taken into account. An infinite time horizon is employed, land conversion is not instantaneous (as assumed in some models), C fluxes associated with many forest management activities (but not control of fire, pests and disease) are included, and account is taken of what happens to the wood after harvest, including their decay (see Table A.2 for data on decay of forest ecosystem components).

The study results are summarized in Figure 10.1. These indicate that upwards of 1.5 million tonnes of discounted C (discounted at 4%) can be sequestered in the region at a cost of about $40 per t or less. This amounts to an average of about 1.3 t ha^{-1}, or about 52 kg ha^{-1} per year over and above normal C uptake. If this result is applied to all of Canada's productive boreal forestland and surrounding marginal farmland, then Canada could potentially sequester some 10-15 Mt of C annually via this option. This amounts to at most 7.5% of Canada's annual Kyoto-targeted reduction, well below the 22% that had been envisioned (Canadian Pulp & Paper Association 2000). This is a rather pessimistic conclusion given that, in general, plantation forests are considered a cost-effective means of sequestering C (Sedjo *et al.* 1995; Adams *et al.* 1999). Again, the reason is that boreal forests are globally marginal at best and silvicultural investments simply do not pay for the most part, even when C uptake is included as a benefit of forest management (van Kooten *et al.* 1993; Wilson *et al.* 1999).

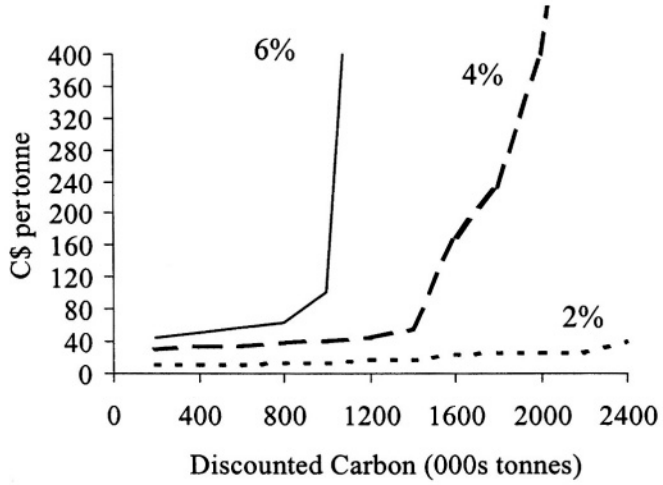

Figure 10.1. Marginal costs of C uptake in a Boreal forest ecosystem, NE British Columbia

There remains a great deal of uncertainty about planting hybrid poplar on a large scale because it has not been done previously. There are drawbacks that limit their viability:

1. Relative to native species, hybrid poplar plantations have negative environmental impacts related to reduced biodiversity and susceptibility to disease (see Callan 1998).
2. If there are transaction costs associated with afforestation, this will increase C-uptake costs above what has thus far been estimated.

3. There is uncertainty about (current and future) stumpage values and prices of agricultural products, and this makes landowners reluctant to convert agricultural land to forestry.
4. Little is known about the potential of wood from afforested land as a biomass fuel (discussed in section 3 below).
5. Research suggests that planting trees where none existed previously decreases surface albedo that offsets the negative forcing expected from C uptake (Berts 2000). Indeed, in some cases, a forestation program may even contribute to climate change rather than mitigating it as expected. This is more of a problem with coniferous than deciduous species, however, although it would not be entirely absent in hybrid poplar plantations.
6. There is the problem of leakages: Large-scale afforestation and/or other forest plantations are bound to lower wood fibre prices, with current woodlot owners (say in the US South) reducing their forest holdings by converting land back to agriculture in anticipation. These are generally ignored in calculating the costs of individual afforestation or reforestation projects. Yet, such leakages can be substantial, even as high as one-half of the C sequestered by the new plantations (Sohngen and Sedjo 1999).

2.3 Forest activities in developing countries and the Clean Development Mechanism

It may be less costly for private companies, such as utilities, to invest in forest activities in developing countries via Kyoto's CDM than to invest in boreal forest regions. This can be seen from Table 10.5, where examples of C-uptake costs for forestry projects in six tropical countries are provided.[3] Plantation forests and agroforestry are profitable even in the absence of C-uptake benefits, while protection of tropical forests or simply delaying (or slowing down) logging activities in tropical regions can yield immediate C benefits at relatively little cost (Frumhoff *et al.* 1998). Clearly, there are going to be few terrestrial C-uptake projects in Canada, Russia, Sweden and maybe even the USA that can compete with projects in developing countries.

The only drawback of the CDM approach is that developing countries may lack political stability, and the required institutions and infrastructure, to make verification and enforcement possible, although this is likely not true of all countries. This increases transaction costs. But some of the problems of developing countries might also apply to developed countries. For example, verification of various potential C sinks, such as wood product and soil sinks, will be difficult no matter where they occur. It

is here that there is a role for environmental NGOs, such as the Forest Stewardship Council (FSC), which can certify private firms to monitor carbon flux in forest ecosystems for purposes of C accounting, much as it currently does in the case of forest management practices. This issue is discussed further in Section 4.

Table 10.5. Estimated net costs of C offset measures, selected developing countries

Country and project	Net cost of C uptake (1997 US $ per tonne)[a]
Brazil	
Plantation: Pulp	–7.2
Plantation: Charcoal	–0.5
Plantation: Sawlogs	–14.7
Thailand	
National Parks & Wildlife Sanctuaries	1.7 to 4.3
Watershed Protection Areas	0.9 to 5.4
Community Woodlot: Eucalyptus	1.0
Semi-public Plantation: Eucalyptus	–3.8
Private-sector Plantation: Eucalyptus	–13.0
Semi-public Plantation: Teak	–2.5
Community Plantation: Teak	–18.5
Agroforestry: Eucalyptus/Maize	–1.2
Agroforestry: Eucalyptus/Fruit Trees	–25.6
Tanzania	
Protected Area	1.3
Agroforestry: Eucalyptus/Maize	–1.8
Public Plantation: Eucalyptus	0.1
China	
Plantation	–12.4 to 1.8
Agroforestry	–13.1 to –1.4
Mexico	
Natural Forest Management: Temperate	–8.3
India	
National Parks	10.4
Natural Regeneration of Degraded Forest (w. harvesting)	–1.8
Enhanced Regeneration of Degraded Forest (w. harvesting)	–0.4
Agroforestry	–4.5
Community Woodlot	–0.8
Softwood Plantations	–1.6
Timber Plantation	–0.6

[a] Negative net costs indicate that the activity yields net benefits over and above C flux benefits.
Source: Frumhoff *et al.* (1998)

3. BIOMASS BURNING AND WOOD SUPPLY

Biomass burning is defined as the conversion of wood biomass into energy by burning in a controlled system. It constitutes an important means for some countries to achieve reductions in CO_2 emissions. For example,

Sweden is hoping to rely more heavily on biomass burning, because other non-fossil fuel options – nuclear and hydro power – are thought to be environmentally unsound. In Canada, the potential for biomass burning also appears considerable due to the extent of its forests. Unlike the use of trees for wood products, biomass burning is approved under current Kyoto definitions. Biomass burning does not lead to potential C leakages such as those that occur when timber from plantations is used for wood products (as discussed above). Indeed, the benefits of C uptake through afforestation are enhanced under current rules when there exist opportunities to use forest biomass in conjunction with wood waste to produce energy that substitutes for energy from fossil fuels (with the reduction in GHG emissions from fossil fuel consumption constituting a credit).

In terms of carbon balance, the benefits of burning biomass to produce energy include the maintenance of an emission-uptake equilibrium (no net flux), the one-time gain in C uptake from initial establishment of a tree plantation and then the annual fossil-fuel offsetting emissions. There is also the potential for capturing carbon in the burning process, thereby reducing total emissions further.

The Canadian forest sector is a large consumer of electricity, much of it purchased from the local/regional provider. The purchased electricity is generated from a variety of sources, including primarily natural gas, coal and hydropower. The forest sector self-generates about half of the power that it uses (Forest Sector Table 1999), but is constrained in many cases from achieving economies of size in power generation by either an inability to sell excess power into the provincial grid or a lack of fibre (Canadian Pulp & Paper Association 2000). In British Columbia, for example, BC Hydro restricts sale of privately generated power into the provincial grid because this would reduce prices and the revenues that the government-owned company could generate. Until recently, sawmills in the Province burned sawdust in beehive burners, but, when this was no longer permitted on environmental grounds, the sawdust was simply put into landfills. A small number of cogeneration plants have been built since the ban, primarily in areas where disposal costs and wood waste volumes are highest.

Wood waste could be a limiting factor in achieving economies of scale in biomass burning, however. As demand for industrial wood waste increases beyond supply, the value of wood fibre from fast-growing energy plantations will increase. If biomass power generation is determined to be economically profitable, farmers may be able to sell biomass at a profit; at least, it might reduce the compensation (private or public) paid to farmers for establishing and maintaining tree plantations, and increase the area economically feasible for afforestation.

Besides the reduction in CO_2 emissions, biomass burning can provide opportunities for industry and communities to reduce their electricity costs if power generators are scaled to their particular requirements. The establishment and operation of biomass systems will increase employment, with most of the jobs created in rural areas where jobs are most threatened by ongoing forest protection measures and mechanization of factors of production.

Wood fuel conversion technologies include direct combustion, cogeneration, gasification, and conversion to liquid fuels. The efficiency of the conversion system determines the reduction in CO_2 emissions through the displacement of fossil fuels. Estimates of emission savings range from 1.7 to 9.0 tonnes of C per hectare per year depending on forest type, discount rates, energy conversion efficiency, and the particular fossil fuel being displaced (Wright *et al.* 1992; van Kooten *et al.* 1999). The cost of substituting wood biomass for coal in electricity production ranges from \$27.60 to \$48.80 per t C, based on a value of \$7.50 per m^3 for hybrid poplar on energy plantations, a substitution ratio of 2.6-4.6 m^3 of wood per t of coal to generate an equivalent amount of energy, and a carbon content of 0.707 t C per t of coal (Marland *et al.* 1995).

Table 10.6. Energy price comparisons for British Columbia, Canada ($C1997)

Wood Residues (assumed conversion factor = 18 GJ per dry tonne)	
Wood residue from pulp and paper mills	\$1.0 GJ^{-1}
Wood residue from wood industry	\$0.56 GJ^{-1}
Wood waste plus plantation wood	\$2.82 GJ^{-1}
Fossil Fuels (based on natural gas, boiler efficiency of 85%, and C emission factor of 0.050 t GJ^{-1})	
Fuel price	\$1.73 GJ^{-1}
Electricity (at \$0.039 per kWh)	\$10.84 GJ^{-1}

Source: Forest Sector Table (1999) and own calculations

As shown in Table 10.6, energy from wood residues can compete with fossil fuels and purchased electricity. This conclusion needs careful scrutiny, however. First, wood residue prices are based on average and not marginal costs, and are only available for small-scale operations where wood is easy to come by. At a larger scale, one would expect much higher raw material (wood) costs. Second, wood fibre prices vary significantly by region depending on residue surpluses or shortages, and environmental regulations. Regional values are not currently available for comparison (Forest Sector Table 1999). If fast-growing plantations are included, estimated costs are \$2.82 per GJ, which is more expensive than fossil fuels, but still cheaper than purchased electricity.

Fossil fuel substitution on a global scale, using 10% of an estimated 3,454 million ha of forested area as a source for biomass energy,

would replace an average of 2.45 Gt C per year. This figure is based on 7 t C ha^{-1} yr^{-1}, while the average C capture rate can vary from less than 0.5 to 12 t C ha^{-1} yr^{-1} depending on the type of forestry being practiced – conventional or plantation. This amounts to some 40% of global fossil fuel emissions of carbon in 1990.

In Canada, the high capital cost of infrastructure, regulation of the electricity market, and the relatively low cost of fossil fuels restrict the economic viability of substituting biomass for fossil fuels in power generation. When we consider global climate change, future energy requirements, availability of supply, and social and environmental values, we find that the benefits of renewable energy sources such as wood biomass outweigh the costs in some, but not all situations.

4. ECONOMIC INSTRUMENTS AND INSTITUTIONS: RESPONSE TO MARKET FAILURE IN FORESTRY

One response to the failure of forest management to account for carbon storage and flux (or market failure) has been to increase emphasis on multiple use management, and even more recently on forest ecosystem management. While managing for multiple use is commonly understood and accepted by foresters, the same cannot be said about ecosystem management (Sedjo 1996). The problem is that it is not at all clear what the objectives of ecosystem management might be – they are vague and ill defined – and there is no way of knowing when objectives are achieved. This makes scientific management difficult if not impossible.

In order to get firms to harvest forest stands at times that confer the greatest benefits to society, it is possible to harness the power of the market (or competition) via taxes and subsidies, and through the use of tradeable carbon (emission and uptake) permits. In practice, governments have eschewed this approach, preferring instead to rely on control – regulation or direct ownership, or a combination of these.

In the past decade, many countries have implemented new forest acts that have included forestry regulations of one form or other (see Wilson *et al.* 1999). Both Finland and Sweden have new forest acts meant to protect nature. However, the most onerous and detailed regulations have been implemented in British Columbia through the Forest Practices Code of 1994, perhaps surprisingly, as BC also has the highest public ownership of forestland of any jurisdiction (see Wilson *et al.* 1999). Countries have also put in place harvest restrictions, particularly by setting aside environmentally important ecosystems. While the purpose of set asides is to protect biodiversity, they also constitute a massive carbon sink (although

the stability of such sinks depends on their susceptibility to fire and/or pests). This has been most evident in the US Pacific North West (PNW) and BC, where large tracts of old growth have been removed from the working forest and protected in perpetuity.[4] The problems with such zoning is that it leads to variances, which have slowly eroded protected areas (Sinclair 2000). Nonetheless, zoning has been promoted in California (Vaux 1973) and BC (Sahajananthan *et al.* 1998) as appropriate means for conserving non-timber amenities, and thus addressing market failure.

There are problems with state intervention via regulation. First, it is likely to be expensive and ineffective in the longer run. Regulations lead to bureaucratic red tape that increases costs. This has been the case in BC where the Forest Practices Code is estimated to add more than $1 billion annually to the costs of harvesting trees on public lands, or some $15-$20 per m^3 (Haley 1996). In comparison, social benefits (including C flux benefits) appear small (van Kooten 1999). A regulatory environment also creates opportunities and incentives for corruption: those enforcing regulations can be bribed in various ways (not always monetary) to overlook certain contraventions of the law (perhaps because regulations can be interpreted in more than one way), while politicians might grant variances to the zoning ordinance in order to gain support ("bribes") from industry or to please voters (*e.g.,* local communities, forest-sector workers). There are suggestions that valuable forested areas in BC Provincial Parks have been removed for logging to support industry and workers, only to be replaced by an equal or larger area of previously logged or poorer-quality forestland (Sinclair 2000). Similarly, in 1997, Venezuela permitted logging in the country's largest forest reserve – the 37,000 km^2 Sierra Imataca rainforest reserve near the Guyanese border – when fibre prices rose (*The Economist* 1997).

Second, if governments are truly concerned about the environment, they need to be more careful in making decisions about land use. Thus, Sinclair (2000) complains that governments have been quick to identify protected ecosystems, but have not made available adequate funds to protect them from encroachment, while Pressey (2000) demonstrates that, in Australia, governments have only put into reserves public lands that are marginal for protection of biodiversity. Governments want to be seen as promoting biodiversity, as providing nature, but are unwilling to incur the budgetary costs that are required. They are also unwilling to rely on markets on ideological grounds, even when there are benefits to so doing (for a discussion, see Sowell 1999; also Pearse 1998).

Finally, a regulatory environment often leads to a classic principal-agent problem. This is truer for regulations involving harvesting methods and silvicultural investments that are aimed at protecting nature than for

the case of zoning or wilderness set asides. With regulations that involve silvicultural prescriptions to provide more nature (greater uptake of carbon), there remains uncertainty (*e.g.,* related to measurement) so that it is not precisely clear when and if the desired outcome has been achieved. Even when outcomes are defined in terms of specific silvicultural tasks, such as establishing trees on a site where there had been no trees previously, there remains a certain amount of ambiguity. For instance, what is the state of trees at the time they are 'established'? What proportion are likely to survive? How many stems need to be planted? Are they appropriate species for the site? Are they native or exotic species, or genetically engineered to grow quickly for a short period in order to satisfy "establishment" and/or perceived C uptake requirements? Are trees subject to disease, and what is the probability that they will survive to maturity and not release C to the atmosphere before then?

While direct intervention by the state can, in principle, lead to greater uptake and storage of C, such intervention often leads to policy failure. Policy failure results from the inability of the authority to provide appropriate (socially optimal) levels of commercial and/or environmental amenities because of political interference and/or bureaucratic bungling (see Hart *et al.* 1997; Shleifer and Vishny 1998; La Porta *et al.* 1999). Therefore, it is important to consider the potential of competition, or markets, to address policy failure related to forestry and global climate change.

Perhaps the most important market-based initiative with respect to forestry and land use is the establishment, beginning July 1, 2000, of the world's first exchange-traded market for carbon uptake credits. This exchange was created in response to increasing international demand by large CO_2 emitters looking to manage risks and purchase C credits, and in anticipation of public policy to meet targeted GHG emission reductions. The carbon-trading market was created by the Sydney Futures Exchange, in conjunction with State Forests of New South Wales and its subsidiary, the New Zealand Futures and Options Exchange; the Chicago Mercantile Exchange is likely to follow (McLean 2000).

While this initiative has essentially by-passed government – indeed precedes political initiatives – public institutions play an important role as a catalyst. In particular, by separating ownership of carbon from the tree, legislation in New South Wales enabled establishment of the carbon exchange. Further, without the courts, it will not be possible to enforce and adjudicate C sequestration contracts that provide information on the carbon sequestered (that it even exists) and the silviculture to be performed (that it has happened). It will likely be left to some mix of initiatives by the private and public sectors to certify C credits. This will be easier in the case of

large CO_2 emitters (buyers) who have the resources to audit the providers (sellers). Sellers might be certified under ISO 9002 (quality systems, including forest inventory and mapping systems) and ISO 14001 (environmental management systems). They might also be certified at the national level or through such ENGO initiatives as the FSC that would certify independent companies who have the expertise to conduct carbon audits and/or certify and audit sellers.

A market for trading C sequestration credits is an important development for several reasons. First, the futures market for C credits – a futures market because it deals with C uptake in the Kyoto commitment period (2008-2012) – establishes a price for C. While not tied to damages, it does provide a useful indicator for both the private sector and policy makers. Further, such a market can be integrated into a larger system of carbon emissions trading; instead of purchasing CO_2-emission permits, companies (or countries) can purchase C uptake credits. Finally, biomass burning projects are likely more profitable with carbon credits than without, because the credits have value.

5. CONCLUSIONS

Despite prolific research on the topic, many issues related to the role of forestry in abating climate change remain to be resolved. Our research indicates that, while researchers have focused on how management affects C storage in the bole, information about non-bole C is limited. We have only begun to estimate the soil C fluxes associated with "improved" land management and land use changes. Even less is known about the costs of the additional associated C uptake.

Likewise, our research indicates that little is known about the supply of wood for biomass burning. We lack knowledge about whether wood waste or fibre from plantation forests designated for biomass burning. The economics of biomass burning are location specific and related to wood fibre availability. They also depend on economic institutions and incentives. Recent research (Suchanek 2001) suggests that it will not be easy to convince farmers to switch their current land uses to incorporate large-block planting of trees; significant subsidies appear to be needed, but these are likely too large relative to other means for reducing atmospheric CO_2. Not surprisingly, farmers are interested in gaining carbon credits for changing agricultural practices so that more organic matter (and thus carbon) is stored in soil; these practices reduce soil erosion, and include minimum tillage and reduced tillage summer fallow. However, the technology of biomass burning is changing, driven by fossil fuel prices and

the desire to obtain carbon credits. What happens in fossil fuel markets and (future) markets for C uptake services will be pivotal in determing the future of wood fibre in biomass burning.

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NOTES

[1] Evidence indicates that forested areas are increasing in developed countries, particularly those in the northern latitudes, so we focus only on deforestation in tropical regions.
[2] Global data on the potential for C uptake via forest management is provided in Appendix Table A.1.
[3] Of course, it is not clear that the same methodology is used to calculate costs per unit of C as in the case of the Canadian studies cited. For example, while the Canadian studies (as well as US ones) discount physical carbon, the Global Environmental Facility recommends against this. Reasons for discounting C in the case of forestry are discussed in more detail by van Kooten *et al.* (1999).
[4] Many studies have examined optimal protection of old-growth forests, with most concerned about irreversibility and quasi-option value (*e.g.* Conrad 1997). Van Kooten and Bulte (1999) employed a deterministic framework, but included all amenity values, particularly C sink and uptake benefits.

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APPENDIX

Table A.1. Global estimates of the costs and potential carbon that can be removed from the atmosphere and stored by enhanced forest management from 1995 to 2050

Region	Practice	C removed & stored (Gt)	Estimated costs ($US $\times 10^9$)
Boreal	Forestation[a]	2.4	17
Temperate	Forestation[a]	11.8	60
	Agroforestry	0.7	3
Tropical	Forestation[a]	16.4	97
	Agroforestry	6.3	27
	Regeneration[b]	11.5 - 28.7	44 - 99
	Slowing-deforestation[b]	10.8 - 20.8	
TOTAL		**60 - 87**	

[a] Refers primarily to reforestation, but this term is avoided for political reasons.
[b] Includes an additional 25% of above-ground C to account for C in roots, litter, and soil (range based on uncertainty in estimates of biomass density).
Source: Adapted from Watson *et al.* (1996, pp.785, 791)

Table A.2. Rates of decay of forest ecosystem components (including wood products) upon harvest

End-use category	Anthropogenic time (years from felling until decay starts)	Decay time (years until all fibre has decayed)
Bark in land fillings	0	8
Bark for burning	0	1
Needles	0	7 to 11
Branches, stumps, stems in forest	0	12
Root system after felling	0	100
Construction material	80	80
Furniture & interiors	20	50
Impregnated lumber	40	70
Pallets	2	23
Losses	0	1
Composites, plywood	17	33
Sawdust	1	2
Pulp/paper	1	2
Fuelwood	0	1

Source: Hoen and Solberg (1994)

Part IV

Agriculture and other sources of sustainable energy

Chapter 11

MODELLING WATER RESOURCE ALLOCATION: A CASE STUDY ON AGRICULTURE VERSUS HYDROPOWER PRODUCTION

Jorge Bielsa and Rosa Duarte

1. INTRODUCTION

In this chapter we propose an economic model for the optimum allocation of water within a given area with the following features. First, the introduction of the institutional, geographical and time scheme under which the water rights are granted. Secondly, the establishment of a modelling framework for these characteristics which influence and are, in turn, influenced by two particular circumstances, namely the irregular conditions of the upstream flows and the possible new requirements of some of the users. Particular attention is paid to the effect of the time and space on water demand and supply conditions.

The problems associated to the management of water in Mediterranean climates are well known, with these essentially resulting from the uncertainty associated with the supply of water in terms of both space and time. Thus, in order for users to be guaranteed the possibility of counting on the necessary surface water resources, volumes and priorities are allocated to different uses by way of water rights. These rights represent the main legal instrument that ranks and shares the uses with respect to space and time.

As Howe *et al.* (1986) have stated 'property rights in water can be completely described only by a definition covering the quantity diverted and consumed, timing, quality and places of diversion and application. Changes in any of these characteristics could potentially affect other water users'. With this being the basic scenario within which water users operate, the literature contains various studies that place emphasis on the need to

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introduce flexibility in the allocation of resources. In this sense, the now classic work of Coase (1960) demonstrates that, once property rights have been established, their exchange by the agents would generally lead to improvements in the Pareto sense. For the particular case of water, the works of Young and Haveman (1985), Gibbons (1986), Howitt (1988), or that of the earlier mentioned Howe *et al.* (1986), are illustrative of how proximity to market situations leads to more efficient allocations of the resource.

The correct definition of water rights (in the terms described above) and of third parties -particularly of the environment- are two of the main problems to which the literature has also given attention. In this regard, Winpenny (1994) carries out an in-depth analysis of the difficulties implied in these definitions and notes that the allocation of water throughout the world is carried out by way of administrative rules, with the market approach being the exception.

In any event, when beginning from the basis of clearly inefficient allocations of the resource, there is an important margin for transactions that would markedly improve this situation. In this line, it is possible to propose allocation systems that, taking into account environmental, institutional and hydrologic restrictions, lead to exchanges that are beneficial for society as a whole.

Against this background, the aim of this chapter is to demonstrate how, for a specific case, incentives can make the existing bureaucratic resource management more flexible. Just as in the works of Houston and Whittesey (1986), Butcher and Wandschneider (1986) or Chatterjee *et al.* (1998), the allocation problem we consider arises out of competition for the water resource between two users, namely agriculture and hydropower. The novel aspect of our work is that the proposed model and the resulting optimum allocation take into account two aspects of Howe's concept of the definition of water rights that have not, in our view, received sufficient attention, *i.e.* timing and place of diversion[1].

These two important aspects will be reflected both in the way the problem is framed and in the main results. Specifically, the problem we are considering is water allocation between users situated in different locations and with requirements at different times of the water year. On this basis, we examine whether it is possible to obtain benefits from a hypothetical bilateral exchange.

Obviously, the fact that we focus on incentives to transactions does not mean that these actually take place. Such exchanges depend to a large extent on legal, hydrologic and, mainly, historical settings. In Spain, for example, the allocation of water is carried out by way of rigid administrative mechanisms and at prices that hardly reflect the transport

and water storage costs. If, to all this, we add that expectations of new supplies of cheap water are constantly being raised by the Public Administration, then it should come as no surprise that the users show only limited interest in transactions which suppose, at the very least, that they have to pay the opportunity costs of the activity which assigns its rights (see Sumpsi *et al.* 1998). Nevertheless, we agree with Howe *et al.*(1986) that it is necessary to demonstrate specific situations of Paretian improvements derived from the exchange in order to convince both policymakers and users of the advantages of these types of systems, as compared to the traditional subsidised supply of new resources.

It is in this context where the time and space dimensions acquire a particular relevance. The current administrative system establishes a series of priorities that are independent of time and space. In this sense, new demands by any user affect the whole system and the way in which water is available for the remaining users can therefore be restricted, depending on where and when the water is required. For example, the current plans for the transfer of water from the Ebro to the Mediterranean basin have been drawn-up with little account being taken of the effects on the time and space distribution of the flows in the basin from which this water is to be transferred. This could result in the disappearance of the Ebro delta, which requires certain minimum stream flows at specific times.

The rest of the chapter is organised as follows. In Section 2, we consider the model that underlies our specific case study. This model includes the specification of the behaviour of two users and the formal representation of the priority of water rights which results from applying current legal regulations. Particular attention is paid to the geographical and time characteristics of these rights. On the basis of a restricted optimisation model, we show that it is possible to obtain an efficient allocation that leads to greater joint profits. Section 3 is devoted to a calibration and empirical application of the model through a simulation of two scenarios: drought and extension of arable land. Section 4 closes the chapter with a review of the main conclusions.

2. AGENTS, VARIABLES AND OPTIMISATION FRAMEWORK

In this Section we propose a model on the basis of which it is possible to obtain water allocations between users. Our aim is to construct this model in such a way that it covers the largest possible number of situations. However, before discussing the model in detail, let us first consider the

agents who intervene, their geographical location and the initial institutional and hydrologic framework.

2.1 The agents

As we can see from Figure 11.1, we consider two reservoirs upon which four types of agent, namely cities, minimum instream flow for environmental reasons, farmers and hydropower depend. The water rights of each of these agents are restricted by the maximum volume that can be used, at any moment in time and by a strict order of priority in the following terms. First, the city users are supplied with a maximum security level. This supposes that there is a prior level of reserves in the reservoirs that cannot be used unless and until the city uses have been satisfied.

Once the drinking water needs have been covered in the above terms, it is necessary to guarantee the minimum flow, which consists of a minimum continuous flow in the natural channel. The next use under this order of priority is that of agriculture. In contrast to the two earlier uses, this requires water for only half the water year, that is to say, during the irrigation period. It is this aspect that gives relevance to the time distribution of the rights and to the possibilities for the transfer of resources from one time period to another through storage in reservoirs. For the sake of simplicity, we consider only two sub-periods in the water year, namely, the irrigation and the non-irrigation periods.

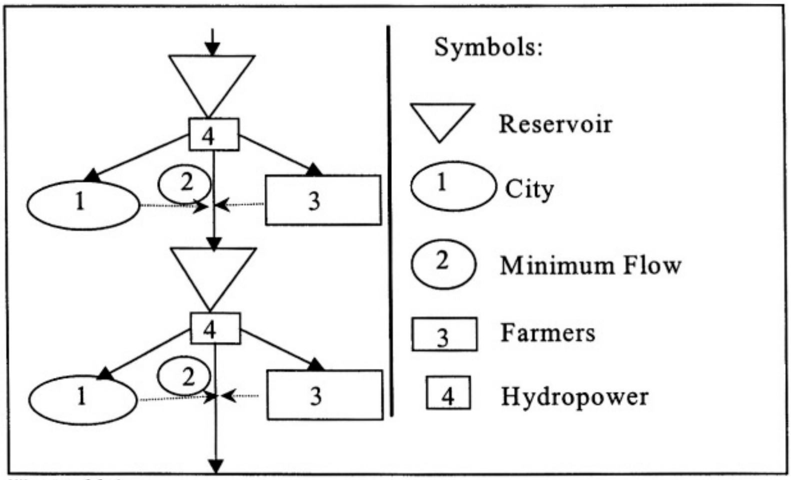

Figure 11.1.

The last agent to appear under this order of priorities is hydropower, in the form of the hydroelectric plants located at the foot of

the reservoir. These plants release water only when the other uses are satisfied in each period. Once all the other users have received the amount of water established in their water right (hereafter referred to as 'allotment') it is possible to accumulate water in the reservoirs in prevision for possible drought periods and until their storage capacity is reached.

All the agents are organised spatially around two systems (upstream and downstream) regulated by two reservoirs that, logically, are interdependent. A scheme established in this way describes a large number of situations that could be represented as particular cases of it. The interdependencies translate into two aspects: first, the agents located downstream are, to some extent, subsidiaries of their homologues and of the upstream priority uses; secondly, the reservoirs are managed in a co-ordinated manner in order to meet the needs of the totality of the users.

For practical purposes, we assume that the city and environmental requirements are given and, whenever possible, coincide with the allotment. By contrast, we assume that both farmers and hydropower have a profit function that depends on the volume of water used. This means that the requirement of the cities and the minimum flow act as mere restrictions, whilst the water used by farmers and hydropower are our main variables.

2.2 Variables

The allotment (maximum quantity established in the water right) and effective applied water levels are represented by Ck_{jt} and Uk_{jt}, respectively, with $k = 1, 2, 3, 4$ types of use; $j = 1, 2$ systems and $t = 1, 2$ sub-periods of the water year mentioned above. We denote by R_j^0 the minimum levels of the reservoirs dedicated to guaranteeing drinking water.

Two important state variables of the model are V_{jt} and R_{jt}. V_{jt} represents the volume of water supply per period in each system and corresponds to the initial reserves (R_{jt-1}), plus the quantity of water it receives, either in the form of the natural upstream inflows of the river (A_{jt}) or from the earlier return flows[2] $(rk_{j-1t}\ Uk_{j-1t})$, with rk_{j-1t} being the rate of return flows of use k in system j-1 and in period t. Thus, there are two flow variables (C, U) and three state variables (R, A, V)[3].

As regards the variable R_{jt} (reservoir reserves of system j at period t), this takes values between 0 and the maximum capacity of the reservoir (R^{max}). Furthermore, and in function of whatever is the amount of the upstream flows and the intensity of the uses, it will take values above or below the security reserve R_j^0. Thus, if the available water is insufficient even for urban uses, the reserve will be null until these are satisfied and,

thereafter, these reserves will have priority over any other use until such a security level ($R_{jt} = R_j^0$) is reached. Once this limit has been exceeded, additional units of water will be kept in the reservoir only if all the other uses are satisfied. These variables, their spatial location and time distribution are presented in Figure 11.2.

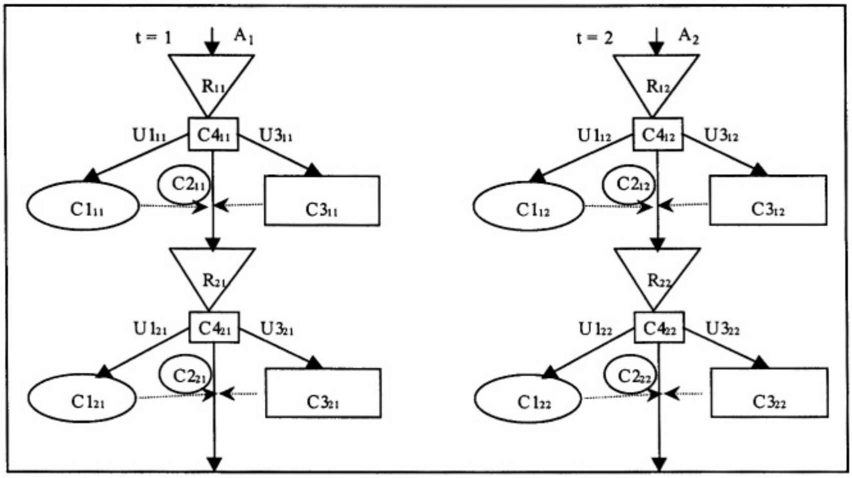

Figure 11.2.

2.3 The model

Farmers cultivate a mixture of *i* different products (*i = 1, 2, ..., n*) with net profits per unit of surface area (with the cost of water also being discounted) of $m^A{}_{ij}$, surface areas per crop of s_{ij} and applied water for each crop and irrigated area of $U3_{ijt}$ (which, in turn, depends on the water needs of the crop (NH_{ij}) and the irrigation efficiency (*e*).

With respect to the hydropower plant, the profit also depends on its unit margin (m^H), on the released flow ($U4_{jt}$), on a conversion independent of these factors in energy, which we denote as α, and on the head of water in the reservoir (h_j) which, in turn, depends on the volume stored in the reservoir $h_j = h_j\,(R_{jt})$. The margin m^H corresponds to the profit obtained by the last unit of energy (Kwh) produced.

The restrictions reflect the two aspects we consider to be essential, that is to say, the water right system and spatial location, with the first of these establishing the order of priority, the allotment and the moment in time at which the use becomes effective.

In function of these criteria and of the places of diversion, we have two possible relationships between the uses: rival and successive (or non -

rival). Two uses are rival if they compete for the same unit of water in the same place (although they do so at different moments in time). By contrast, two uses are successive if the withdrawal of one unit of water on the part of one of them does not prevent its use by the other.

Under this general scheme, we can propose a model of optimum allocation between the uses with the following objective joint profit function and restrictions:

$$Max\ M = \sum_{t=1,2}\sum_{j=1}^{2}\sum_{i=1}^{n} m_{ij}^{A}\ s_{ij}U3_{ijt}(NH_{ij};e_{ij}) + m^{H}\alpha\sum_{t=1,2}\sum_{j=1}^{2} h_j(R_{jt})U4_{jt}$$

subject to:

$$V_{jt} = R_{jt\text{-}1} + A_{jt} + V_{j\text{-}1t} - (1 - r1_{j\text{-}1t})U1_{j\text{-}1t}$$
$$-(1 - r3_{j-1t})U3_{j-1t} - R_{j-1t} \qquad (11.1)$$

$$R_{jt} = Min\{R_j^{\max}; Max[V_{jt} - Max(C4_{jt}; C1_{jt} + C3_{jt} +$$
$$Max(C2_{jt}; Max(C4_{j+1t}; C3_{j+1t} + C1_{j+1t} + C2_{j+1t} - R_{j+1t-1})));$$
$$Min(R_j^0; R_{j+1t-1} + V_{jt} - U1_{jt} - U1_{j+1t}; V_{jt} - U1_{jt})]\} \qquad (11.2)$$

$$U1_{jt} = Min\{C1_{jt}; V_{jt}\} \qquad (11.3)$$
$$U2_{jt} = Min\{C2_{jt}; V_{jt} - U1_{jt} - R_{jt}\} \qquad (11.4)$$

$$U3_{jt} = Min\left\{C3_{jt}; Max\begin{bmatrix} 0; V_{jt} - U1_{jt} - R_{jt} \\ -Max\left[U2_{jt}; U1_{j+1t} + U2_{j+1t} - R_{j+1t-1}\right]\end{bmatrix}\right\} \qquad (11.5)$$

$$U4_{jt} = Min\{C4_{jt}; V_{jt} - R_{jt}\} \qquad (11.6)$$

The relationship between effective uses and water rights (priority and volumes) are reflected in the restrictions in the following terms: the water used by a set of successive uses will be the highest of all of them, whilst from amongst a group of rival uses, it will be their total. For example, in restriction 11.5 we can see how $U2_{j,t}$ and $U1_{j+1,t}$ are successive uses, whilst this $U1_{j+1,t}$ is a rival offstream use with respect to $U2_{j+1,t}$.

Furthermore, the order of priority is reflected in the fact that, for each activity, the water used will be the total available volume (V_{jt}), minus

the sum of the amounts consumed by rival offstream uses which have a priority over that activity. In any event, any user can apply more water than the allotment established in its water right. This last aspect justifies that initial minimum option of restrictions 11.2 to 11.6. Given that we have two systems, the variables in *j+1* and *j-1* are null for *j=2* and *j=1*, respectively.

The spatial structure is also implicit in the restrictions, *i.e.,* between two users of the same type, the user which is located further upstream will have priority. Furthermore, the state variable R_{jt} takes into account all the requirements located downstream. Thus, the demands of system 2 condition the available reserves in the whole system at any given time.

As we can note, the level of joint profit depend both on the volume of supply of water and on the time and spatial structure of the water rights. More detailed information about the behaviour of reserves and joint profit function for different availability of water can be obtained from the authors upon request.

On this basis, we are in a position to carry out a comparative analysis with the following steps. First, we define a starting point situation according to which, for the sake of simplicity, the supply and the requirement coincide exactly in space and time. This is the situation that arises in the case where the supply of water is exactly that necessary in order to satisfy all the water rights under the terms and in the places established. Secondly, we suppose a change in the initial conditions in two directions: a fall in water supply (drought) and an increase in agricultural requirements. We then evaluate and compare the two allocations, namely, that resulting from the strict application of the current water rights and that resulting from the joint profit optimisation exercise.

3. APPLICATION OF THE MODEL TO A CASE STUDY

In this Section we apply the model in order to represent and solve two specific water allocation problems. Our case study rests on two types of data: that of system 1, which is real and has served to calibrate the model, and that of system 2, which is simulated.

3.1. The starting-point situation

The starting data for system 1 come from the Vadiello reservoir, located in North-eastern Spain. The requirements are well delimited in this area, as can be seen from Figure 11.3. Data about these requirements were obtained from CHE (2000) and MAPA (1999). Furthermore, the security reserves for urban use are 5 and 2.5 Hm^3, respectively, in each system, whilst the

maximum capacity of the reservoir is 16 Hm^3 in the two cases. The second system is simulated on the basis of data from the first, considering that its demands are one half (except for the minimum flow, where it seems reasonable to assume that this will be the same throughout the length of the river). The data on cultivated surface area and agricultural profits have been taken from the real situation found in our area of study and translated to the second system, copying the share of crops and the net margin per hectare corresponding to the upstream system.

Figure 11.3 represents a supply-demand equilibrium for a given upstream flows regime (that of the Vadiello Reservoir in an average water year). As we can see, all the water rights are satisfied in the place and time established; that is, there is no deficit for any sector.

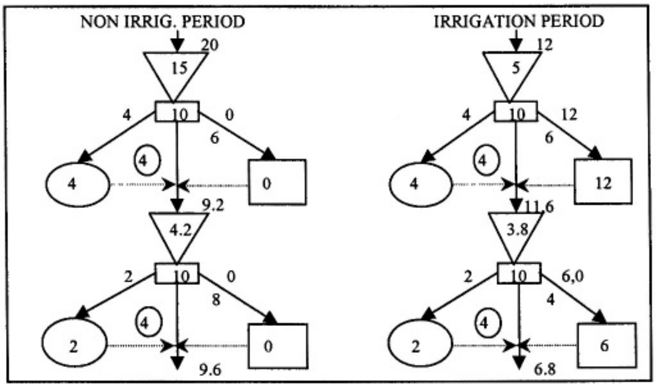

Figure 11.3. Starting point situation

On the basis of a situation of equilibrium such as that described above, we can consider two types of problem that might arise as a consequence of changes in the supply and/or demand conditions: first, a situation of drought, assuming a fall in the water supply of 30% (*i.e.,* a fall in upstream inflows); secondly, an increase in the surface area under irrigation of 700 hectares within system 2 (*i.e.,* an increase in the system 2 irrigation needs). In this latter case, the irrigation-based farmers operating within this system wish to have as much surface area under cultivation as their counterparts operating within system 1 (we assume a constant distribution of crops). It should be noted that we are dealing with an optimisation problem based on an annual time horizon.

3.2 Specification of the theoretical model

We reduce both problems (drought and increase in downstream requirements) to the same terms: calculate the changes in the operational

regime of the hydropower plant that are necessary in order to maximise the joint agriculture-hydropower profit. The resolution of this problem determines certain levels of reservoir-stored water R_{jt} in both periods, various changes in hydropower allotments and, of course, changes in profits for both users.

In order to make the theoretical model operative, a specific profit function is constructed such that $m^A{}_{ij}$ corresponds to profit per hectare, *i.e.,* the net margin minus other indirect costs, as these are defined in agricultural accounting (*e.g.* MOPTMA, 1993). As we can see, we assume linear technology. Furthermore, m^H is determined as 8 pesetas/Kwh, the restated value of the margin for hydropower production that appears in the same document. The head is estimated through a function calibrated for the real data of the Vadiello reservoir, $h_j = b\ ln(R'_{jt})$, with R'_{jt} being the average reserves in each period. The best fit of the head of the reservoir and the reserves is obtained through a logarithmic function with coefficient 8.2323. Finally, α is the conversion independent of the released flow and head in energy (2180 Kwh/Hm^3).

In system 1, there are 1400 hectares of irrigated area, distributed between four types of crops: cereals, 55%; industrial crops, 29%; vegetables, 15%; and fruit, 1%. In all cases, we assume an irrigation efficiency of 47% (see Bielsa, 1999). In system 2, the number of hectares under irrigation is 700, whilst the distribution of the crops and the irrigation efficiency is assumed to have the same structure as in system 1. Both cases, and their associated reallocations, are described in the following sub-sections.

3.3 Case 1: Reallocation in response to drought

The problem here takes the form of a reduction in the upstream flows of 30%, *i.e.,* a ‘typical’ dry year[4]. Table 11.1 shows the earlier mentioned changes in the operational regime that are necessary in order to maximise the joint agriculture-hydropower profit, as well as the consequences of these changes in terms of reserves time distribution (R_{jt}). This table contains three blocks for each system: the starting point, the case of drought for current water rights and the distribution of water rights resulting from the maximisation of the joint profit for this new situation (optimum solution).

Under the assumption of current rights, and following its order of priority, deficits appear in the second period of the dry year. For the hydropower use of system 2, these deficits take the form of the difference

Table 11.1. Fall in water supply of 30% (Drought), Upstream flow of 22.4 Hm^3

System 1	Starting Point		Current Rights		Optimum Solution		System 2	Starting Point		Current Rights		Optimum Solution	
	t=1	t=2	t=1	t=2	t=1	t=2		t=1	t=2	t=1	t=2	t=1	t=2
A_{1t}	20.0	12.0	14.0	8.4	14.0	8.4	A_{2t}	0.0	0.0	0.0	0.0	0.0	0.0
V_{1t}	25.0	27.0	19.0	17.2	19.0	19.4	V_{2t}	14.2	15.8	13.2	11.2	9.7	12.2
$C1_{1t}$	4.0	4.0	4.0	4.0	4.0	4.0	$C2_{2t}$	2.0	2.0	2.0	2.0	2.0	2.0
$C2_{1t}$	4.0	4.0	4.0	4.0	4.0	4.0	$C2_{2t}$	4.0	4.0	4.0	4.0	4.0	4.0
$C3_{1t}$	0.0	12.0	0.0	12.0	0.0	12.0	$C3_{2t}$	0.0	6.0	0.0	6.0	0.0	6.0
$C4_{1t}$	10.0	10.0	10.0	10.0	8.0	14.4	$C4_{2t}$	10.0	10.0	10.0	10.0	6.0	9.7
$U1_{1t}$	4.0	4.0	4.0	4.0	4.0	4.0	$U2_{2t}$	2.0	2.0	2.0	2.0	2.0	2.0
$U2_{1t}$	4.0	4.0	4.0	4.0	4.0	4.0	$U2_{2t}$	4.0	4.0	4.0	4.0	4.0	4.0
$U3_{1t}$	0.0	12.0	0.0	4.2	0.0	6.4	$U3_{2t}$	0.0	6.0	0.0	2.7	0.0	3.7
$U4_{1t}$	10.0	10.0	10.0	10.0	8.0	14.4	$U4_{2t}$	10.0	10.0	10.0	8.7	6.0	9.7
Net Demand	10.0	22.0	10.2	12.2	8.0	14.4	Net Demand	10.0	12.0	10.0	8.7	6.0	9.7
R_{1t-1}	5.0	15.0	5.0	8.8	5.0	11.0	R_{2t-2}	5.0	4.2	3.8	3.2	2.5	3.7
R_{1t}	15.0	5.0	8.8	5.0	11.0	5.0	R_{2t}	4.2	3.8	3.2	2.5	3.7	2.5
Deficit							Deficit						
1Urban	0.0	0.0	0.0	0.0	0.0	0.0	1Urban	0.0	0.0	0.0	0.0	0.0	0.0
2Min. flow	-2.0	-2.0	-2.2	0.0	0.0	0.0	2Min. flow	-4.0	0.0	-4.0	0.0	0.0	0.0
3Irrigation	0.0	0.0	0.0	7.8	0.0	5.6	3Irrigation	0.0	0.0	0.0	3.3	0.0	2.3
4Hydropower	0.0	0.0	0.0	0.0	0.0	0.0	4Hydropower	0.0	0.0	0.0	1.3	4.0	0.3
R_1^0	0.0	0.0	0.0	0.0	0.0	0.0	R_1^0	0.0	0.0	0.0	0.0	0.0	0.0
Hydr.Prof*	0.33	0.33	0.28	0.28	0.30	0.30	Hydr.Prof*	0.22	0.20	0.18	0.15	0.16	0.16

The modified values of the variables and the resulting deficits appear in bold type.
All data in Hm^3 except: Hydr.Prof*: Hydropower profits in pesetas per cubic meter.

between the compulsory withdrawals from the reservoir for the population or for the minimum flow (whichever is the highest) and the releasing demands of that activity. Agriculture only counts on the water left to it by urban requirements and the security stock in the reservoir, with the remaining amount it needs in order to meet its requirements constituting its deficit. As can be noted, the fall in precipitation takes the form of a lower quantity of water stored in the reservoir, a situation that remains throughout the year. Net demand shows the volume of water withdrawn from each reservoir to meet the requirements.

Given that the hydroelectric value of released water depends on the head of the reservoir (and, therefore, on the volume of reservoir reserves), each one of the periods has an associated value of the energy per unit of water used. This value appears in the bottom row of the table.

In the optimum solution, the hydropower plant will change the releasing timetable such that it renounces a part of its initial allotment in the first period. In exchange, hydropower has more water rights in the second period and a higher profit per unit of released water, due to an increase in the level of water stored in the reservoir. In this way, agriculture counts on a larger availability of resources during the irrigation season, which is equivalent to the drought having a lower impact on profits and loss account. The allocation of resources in the optimum solution is presented in Figure 11.4.

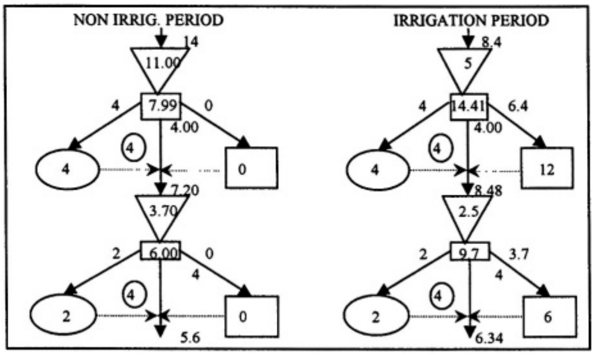

Figure 11.4. Optimum solution

Therefore, if both parties reach an agreement such as that suggested by the optimum solution, an improvement will be achieved in the Pareto sense, as compared to the case in which there is no agreement. This is illustrated in Table 11.2, which presents the increase in profits from the earlier mentioned change in allotments. Therefore, reallocation of water is expected to generate gains in this case.

Table 11.2. Profits in a drought situation under current rights and optimum solution

	PROFITS [a]			
SECTOR	STARTING POINT	CURRENT RIGHTS	OPTIMUM SOLUTION	PROFIT INCREASE
HYDROPOWER	10.86	8.71	9.29	0.58
AGRICULTURE	78.44	30.24	43.93	13.68
JOINT	89.30	38.95	53.21	14.26

[a] The figures are expressed in millions of pesetas, whilst the profits are the total profits of each sector.

Thus, the figures show that it is possible to establish option agreements related to rainfall conditions (in drought years) between farmers and electricity producers that have the effect of reducing the agricultural losses without diminishing the hydropower profits. These agreements represent a type of drought insurance for agriculture, implying an increase in their effective allocations of water stored in the reservoirs at the beginning of the irrigation season as a result of a reduction in the hydropower allotment in the non irrigation period.

Whilst it would be interesting to study the specific legal form in which this agreement could be reached, this lies beyond the scope of our chapter. Here, we only aim illustrating that such an arrangement is, at least on the basis of real data, interesting for both parties.

3.4. Case 2: Reallocation in response to extension in surface area under irrigation

In this case, we assume that there is a plan to double the surface area under irrigation in system 2, while leaving the distribution of crops unchanged. This supposes a permanent deficit of 5.9 Hm^3 for the agricultural sector operating in this system. In fact, it is not possible to meet the additional requirements created by these newly irrigated areas on the basis of the water supply available in an average year, taking into account current hydropower time-distribution allotments.

In such circumstances, we cannot speak of a lack of rainfall, but rather of an increase in requirements that exceeds the possibilities of the current water rights system to satisfy them. Under market conditions this deficit could be met through a relative increase in the price of the good, which is now more scarce. However, given the earlier mentioned institutional structure that operates in Spain, it cannot be expected that such a change will be introduced, at least in the short term.

Table 11.3. Extension of surface area under irrigation of 700 hectares

System 1	Starting Point		Current Rights		Optimum Solution		System 2	Starting Point		Current Rights		Optimum Solution	
	t=1	t=2	t=1	t=2	t=1	t=2		t=1	t=2	t=1	t=2	t=1	t=2
A_{1t}	20.0	12.0	20.0	12.0	20.0	12.0	A_{2t}	0.0	0.0	0.0	0.0	0.0	0.0
V_{1t}	25.0	27.0	25.0	26.8	25.0	25.0	V_{2t}	14.2	15.8	13.2	14.6	13.7	17.3
$C1_{1t}$	4.0	4.0	4.0	4.0	4.0	4.0	$C2_{2t}$	2.0	2.0	2.0	2.0	2.0	2.0
$C2_{1t}$	4.0	4.0	4.0	4.0	4.0	4.0	$C2_{2t}$	4.0	4.0	4.0	4.0	4.0	4.0
$C3_{1t}$	0.0	12.0	0.0	12.0	0.0	12.0	$C3_{2t}$	0.0	6.0	0.0	12.0	0.0	12.0
$C4_{1t}$	10.0	10.0	10.0	10.0	12.0	20.0	$C4_{2t}$	10.0	10.0	10.0	10.0	6.0	14.8
$U1_{1t}$	4.0	4.0	4.0	4.0	4.0	4.0	$U2_{2t}$	2.0	2.0	2.0	2.0	2.0	2.0
$U2_{1t}$	4.0	4.0	4.0	4.0	4.0	4.0	$U2_{2t}$	4.0	4.0	4.0	4.0	4.0	4.0
$U3_{1t}$	0.0	12.0	0.0	12.0	0.0	12.0	$U3_{2t}$	0.0	6.0	0.0	6.1	0.0	8.8
$U4_{1t}$	10.0	10.0	10.0	10.0	12.0	20.0	$U4_{2t}$	10.0	10.0	10.0	10.0	6.0	14.8
Net Demand	10.0	22.0	10.2	21.8	12.0	20.0	Net Demand	10.0	12.0	10.0	12.1	6.0	14.8
R_{1t-1}	5.0	15.0	5.0	14.8	5.0	13.0	R_{2t-2}	5.0	4.2	3.8	3.2	2.5	7.7
R_{1t}	15.0	5.0	14.8	5.0	13.0	5.0	R_{2t}	4.2	3.8	3.2	2.5	7.7	2.5
<u>Deficit</u>							<u>Deficit</u>						
1Urban	0.0	0.0	0.0	0.0	0.0	0.0	1Urban	0.0	0.0	0.0	0.0	0.0	0.0
2Min. flow	-2.0	-2.0	-2.2	-1.8	-4.0	0.0	2Min. flow	-4.0	0.0	-4.0	0.0	0.0	0.0
3Irrigation	0.0	0.0	0.0	0.0	0.0	0.0	3Irrigation	0.0	0.0	0.0	5.9	0.0	3.2
4Hydropower	0.0	0.0	0.0	0.0	0.0	0.0	4Hydropower	0.0	0.0	0.0	0.0	4.0	-4.8
R_1^0	0.0	0.0	0.0	0.0	0.0	0.0	R_1^0	0.0	0.0	0.0	0.0	0.0	0.0
Hydr.Prof*	0.33	0.33	0.33	0.33	0.32	0.32	Hydr.Prof*	0.22	0.20	0.18	0.15	0.16	0.16

Again, the optimisation exercise shows that it is possible to establish agreements, which will now be of a permanent character, to improve the situation of both users. However, and by contrast to the earlier case, we are now not dealing with two different situations, depending on whether we are referring to a 'normal' or to a dry year. Rather, we are considering two possible distributions of the resource over time. The following tables and figures illustrate the three reference scenarios: the starting point situation and the two possible allocations under new agricultural requirements, that is to say, the maintenance of current water rights or reallocation in a optimum solution provided by the maximisation results.

The exchange will take the form of the hydropower plant of system 1 releasing freely (which, under maximisation, will lead to the releasing of 12 Hm^3 in the first period and 20 in the second). For its part, the plant in system 2 will have to renounce 4 Hm^3 of its water rights during the first period in exchange for practically free releasing in the second.

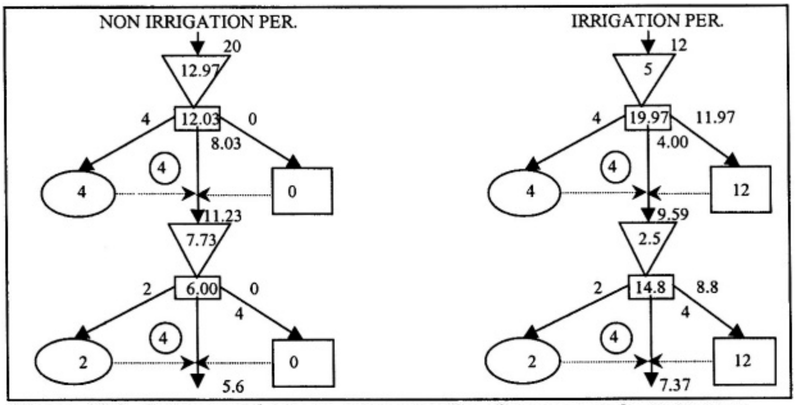

Figure 11.5. Optimum solution to extension of surface area under irrigation

In this way, agriculture (both in system 1 and 2) will find itself in a position where practically all the water it requires in the irrigation period will be available from the water stored in the reservoir during the non-irrigation period. The 3.2 Hm^3 of agricultural deficit that remains in the optimum solution for system 2 is independent of the operational regime. In fact, there is simply not enough water to cover all requirements. Once again, the optimum solution shows itself to be superior to that of current rights, given that both users achieve an increase in their profits. These profits and the gain between the two options are illustrated in Table 11.4.

In summary, the results show that, in the face of a scarcity of resources, negotiating on the distribution of the water rights might not only mitigate the losses resulting from such a scarcity, but could also improve

the joint profit of the system. Depending on the case, these negotiations could be transformed into permanent agreements that would suppose a change in the space and time distribution of the resources.

Table 11.4. Profits under current rights and optimum solution with extension of surface area

	PROFITS			
SECTOR	STARTING POINT	CURRENT RIGHTS	OPTIMUM SOLUTION	PROFIT INCREASE
HYDROPOWER	10.86	9.94	13.55	3.61
AGRICULTURE	78.44	78.88	90.61	11.74
JOINT	89.30	88.82	104.16	15.34

4. CONCLUSIONS

The economic literature contains many examples of how transactions between agents can give rise to efficient allocations and improvements in the Pareto sense. However, allocation of water in Spain has followed procedures very distinct from those recommended by Coase. Thus, in this country water rights are allocated rigidly according to administrative regulations. As a result, exchanges are the exception rather than the rule, and new downstream demands at subsidised prices can be promised by the authorities without taking into account their real upstream effects. Although there are clearly important reasons to question the capability of the market system to efficiently allocate a resource such as water, it is no less true that there are many situations in which the re-allocation of rights could be beneficial for society as a whole.

As a consequence, there is a wide field of study available to us regarding possible exchanges of water rights between one activity and another. In this chapter, we are particularly concerned with the possible benefits of these transactions, rather than the legal or institutional form used to bring them about. We would simply remark that, in general terms, any legal reform should be aimed at ensuring that the agents perceive the opportunity cost of the water they are using.

In this context, it is essential to have a correct definition of water rights in all its dimensions, *i.e.,* quantity, quality, spatial location and time. These last two dimensions have sometimes been ignored in the literature and constitute the central focus of our work and its main contribution. Our central objective is to illustrate the form in which both dimensions can be incorporated in the search for optimum allocations. For this reason, we

have chosen a situation in which two users (agriculture and hydropower) compete for the water resources of a river in both space and time.

Specifically, we consider what would be the optimum allocation of water between the users when there is a scarcity of the resource. That is to say, we try to determine how water should be allocated in order to increase the profit, or mitigate the losses, derived from that scarcity. This process for the optimisation of the agents' profits (in our case, those of farmers and hydroelectric plants) is conditioned by institutional as well as hydrologic, geographical and time aspects. We construct an optimisation model that incorporates the legal order of priority over the water held by each user and places their requirements in space and time.

The empirical analysis is focused on analysing the requirements (from cities, minimum flow, farmers and hydroelectric plants) associated with two interrelated reservoirs managed in a co-ordinated form. This approach allows us to extend the range of real situations that can be simulated. In this chapter we simulate two specific situations of competition for a scarce resource, namely a reduction in streamflow and an increase in irrigation requirements. The results demonstrate the existence of incentives for the hydroelectric plants to review their operational plan in such a way that, at least in some cases, they can assign their rights to agriculture. In these circumstances, we find that making property rights more flexible increases the joint profits of the two types of users.

We believe that an approach of this type would allow us to advance in the necessary integration of the spatial characteristics of water an in economic context. Nevertheless, we clearly cannot forget some important aspects which, although not reflected here, represent natural extensions of this work. Thus, and given the importance of certainty of water supply in the operation of the model, it would be interesting to introduce probability functions of the different levels of upstream flows as well as to obtain the most beneficial allocations in this probabilistic context. Bearing in mind this uncertainty, such allocations would be understood as those which suppose higher profits. Similarly, a consideration of the quality of the water used, both in the definition of property rights and in the allocation process, constitutes a further logical extension of this chapter.

ACKNOWLEDGEMENTS

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NOTES

[1] Harpman (1999) or Edwards *et al.* (1999) are two good examples of the treatment of timing in the hydropower operation in the context of environmental constraints.
[2] In Mediterranean climates, the volume of water available (precipitation less plants and crops-transpiration) come fundamentally from the upper reaches of the rivers and are minimal in the mid and lower stretches. That is to say, in our case $A_{2t} = 0$. As regards the return flows coming from system 1, note that these correspond both to instream and non-rival uses (minimum flow, whose rate of return flows is 1), as well as to irrigation and urban uses (with rates of return flows of 0.2 and 0.8, respectively).
[3] R and V could be state or flow variables, depending on how we use them. In our approach, we consider their value as a fixed quantity per year and period, no matter how their distribution along the periods are.
[4] Water supply follow a stochastic process that is characterised according to a Normal distribution. The typical dry year will be that which leaves a reduced percentage of the years (for example, 2.5%) 'to its left'. This means that a guarantee of 100% is not considered as possible in any case, but simply that the risk is delimited to certain lower levels in the absence of this stochastic view.

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Chapter 12

DEVELOPMENT AND IMPLEMENTATION OF THE DANISH CENTRALISED BIOGAS CONCEPT – FINANCIAL ASPECTS

Kurt Hjort-Gregersen

1. INTRODUCTION

The objective of this chapter is to give a general understanding of the Danish centralised biogas plant concept, its economic achievements, and the preconditions, under which economically feasible plants can be established.

The biogas development programme has been supported by a follow up programme, in which technical experience and economic results have been monitored, analysed, and communicated over the last decade. This chapter is largely based on experience and literature reports from this work.

The interest of biogas plants in Denmark arose in the early seventies as a consequence of the oil crisis. A number of small plants were constructed on an experimental basis, but they were closed down later due to technical problems and unsatisfactory energy production. However, the idea of biogas production was kept alive, and in the early eighties the centralised biogas plant concept was developed. The idea was that a centralised plant should supply heat and electricity to a local village. Three plants of this kind were established in the mid eighties. Later, as environmental consequences of manure application were recognised, legislation on manure handling and utilisation was strengthened. Considerable manure storage capacity was required, and maximum levels of manure application were imposed. It emerged that centralised biogas plants could play a new role, not only as energy producers, but also as providers of manure storage facilities and manure distributors. In addition, centralised biogas plants proved to represent an appropriate way of organic waste recycling.

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Consequently, centralised biogas plants developed from solely energy production plants into integrated energy production, waste treatment and nutrient redistribution facilities.

Recognising that centralised biogas plants make a significant contribution to solving a number of environmental problems in the fields of agriculture, waste recycling and greenhouse gas reduction, the Danish government has supported the development in different ways; an appropriate legislative framework, research and development programmes, investment grants and other subsidies. As a result, today 20 centralised biogas plants are in operation in Denmark.

The overall purpose of the Danish biogas development programme is to contribute to fulfilment of national ambitions in renewable energy production as a tool of green house gas mitigation and organic waste recycling.

2. THE CENTRALISED BIOGAS PLANT CONCEPT

Most of the biomass resources applicable to biogas plants in Denmark is livestock manure, mainly slurry. Livestock production is concentrated in the western parts of the country. Consequently, most centralised biogas plants are placed in these areas. Slurry is transported in vehicles to the biogas plants. Organic waste from food industries, found in the same areas, is also applied to the biogas plant. Some plants also treat source sorted household waste.

At the biogas plant the biomass is digested in anaerobic digestion tanks, which include sanitation facilities that ensure pathogen kill to a satisfactory level. After 12 – 25 days the now digested manure is transported by vehicle to the slurry storage tanks at the farms or near the fields where the slurry is end-used as a fertiliser. In Figure 12.1 a future separation option is stipulated, which will presumably be implemented when the appropriate technology is developed, as it becomes more evident that a further distribution of nutrients is required in order to reach a higher level of sustainability in manure handling and utilisation for agriculture as a whole. In this respect technologically advanced separation systems are required. If centralised biogas plants turn out to control these technologies the way is opened for a wider adoption of biogas plants in many regions of the world.

The biogas that emerges during the anaerobic digestion process is converted into heat and power in a combined heat and power generation facility. Power is sold to the electricity grid, and heat is sold through a district heating system.

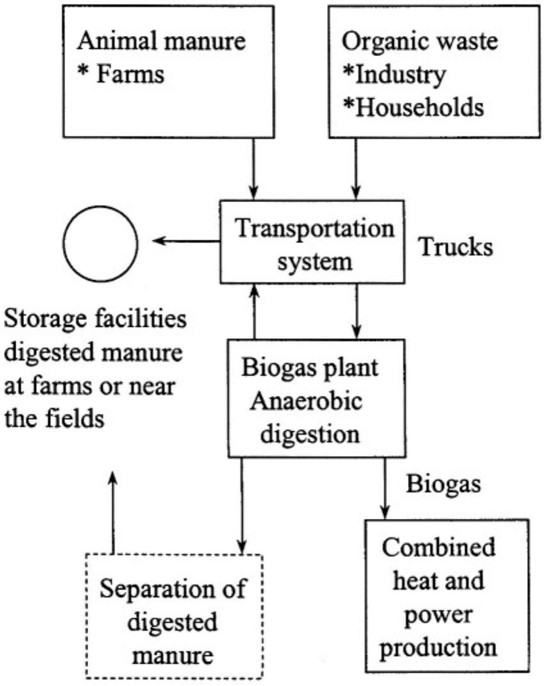

Figure 12.1. The centralised biogas plant concept (Hjort-Gregersen 1999)

3. KEY FIGURES FROM EXISTING PLANTS CONSTRUCTED FROM 1990 – 1997

The existing plants vary greatly in size and design. The largest plant, measured in per day biomass treatment, Ribe, with 79 manure suppliers, applied 444 m^3 of biomass per day in 1998, and the smallest plant shown in Table 12.1, Hodsager, with only 6 manure suppliers, applied 51 m^3 of biomass per day. Normally approx. 75 % of the biomass application is manure, and approx. 25 % is organic waste. Table 12.1 shows some key figures from 12 plants constructed from 1990 to 1997. Another two plants were constructed in 1997 and 1998 but existing data from these plants do not include a whole year of normal operation.

Considerable variation appears in biomass treatment capacity and thus biogas production. It also appears that gas yield, defined as biogas

production per m^3 biomass applied is relatively variable. This is due to the amount and quality of the available biomass resources.

Table 12.1 also shows investment costs in prices of the year of construction. For the plants in Hodsager, Filskov, Snertinge and Blåhøj other investment costs cover a wood-chip burning plant and a district heating system. The Studsgård plant includes a slurry pumping system, and the Lintrup plant was originally equipped with a reversed osmosis slurry separation system. Finally Table 12.1 shows investment grants, and a grant ratio as a percentage of total investment costs.

4. THE OVERALL FRAMEWORK IN WHICH THE ENLARGEMENT OF PLANTS WAS POSSIBLE

Making a valuable contribution in solving a wide range of environmental problems, centralised biogas plants help achieving general government environmental and energy targets.

In the field of environment it is an official government ambition to achieve a 20 % reduction of the 1988 CO_2 emission level by 2005 (Danish Ministry of Environment and Energy 1996), and that 30 % of domestic waste should be recycled by 2004. (The long-term target is 50 %) (Danish Ministry of Environment and Energy 1998) As far as energy aspects are concerned, it is an official government ambition that biogas production from manure based biogas plants, landfill gas collection facilities, and sewage sludge treatment facilities should increase from some yearly 2 PJ in 1995 to 6 PJ in 2005 and 20 PJ in 2030, of which 15 PJ derives from manure and organic waste. (Danish Ministry of Environment and Energy 1996; Al Saedi *et al.* 2000).

The centralised biogas concept is considered as an important tool in achieving the above mentioned targets. The enlargement of plants have been encouraged in several ways by the Danish government, primarily by providing the Energy Research Programme and the Renewable Energy Development Programme, which have provided grants for R & D projects and for reviews, pilot or demonstration projects. These programmes have been supported by follow-up programmes, in which experience gained have been collected, analysed and communicated to farmers, plant operators, advisors, plant constructors and authorities. Furthermore, a set of regulations of the handling and utilisation of animal manure and organic waste has been implemented, which is often referred to as 'the legislative push' (Al Saedi *et al.* 2000). A 6-9 months slurry storage capacity is required, and restrictions on manure application on land have been introduced. Organic waste can no longer be disposed in landfills, and

Table 12.1. Key figures from existing plants established 1990 – 97 (Hjort-Gregersen 1999)

	Units	Ribe	Lintrup	Lemvig	Hodsager	Hashøj	Thorsø	Århus	Filskov	Studsgård	Blåbjerg	Snertinge	Blåhøj
Year of construction	-	1990	1990	1992	1993	1994	1994	1995	1995	1996	1996	1996	1997
Digester volume	m^3	4650	6900	7000	880	2900	4600	7500	880	6000	5000	2800	2800
Process temperature	m/t [a]	t	m	t	m	m	t	m	t	t	t	t	t
Biomass per day 1998	m^3	444	354	428	51	126	315	382	82	305	315	120	83
Manure suppliers	-	79	62	80	6	17	75	45	7	50	58	14	15
Manure 1998	$1000m^3$	119	91.3	119	12	27.5	91.7	122	18.5	87.2	89.5	29	23.1
Crop residuals 1998	$1000m^3$				0.2		0.03		0.02				0.2
Organic waste 1998	$1000m^3$	43.1	37.8	36.9	6.2	18.7	23.2	17.4	11.5	24.2	25.4	14.8	7
Biogas in total 1998	$1000m^3$	4762	3718	5302	656	2504	3281	3860	1224	5841	3300	1694	1353
Organic waste ratio	%	26	29	24	34	40	20	12	38	22	22	34	23
Biogas-yield	m^3/m^3	29	29	34	35	54	29	28	41	52	29	39	45
Investments													
Biogas plant	1000Dkr	28950	32310	43330	6700	18300	25600	54200	9500	46550	35400	18600	16500
Vehicles	1000Dkr	3700	3060	3570	500	1200	3500	-	700	3700	3500	1200	400
Storage tanks	1000Dkr	12600	2380	8300	-	2300	-	-	1000	2850	3000	1200	400
Other investments	1000Dkr	-	5800	-	12000	-	-	-	12000	2600	-	26800	16100
Investment grants	1000Dkr	17700	16830	14200	3900	5100	6300	10840	2500	13900	9700	9200	6900
Grants ratio	%	39	39	26	20	23	22	20	11	25	23	19	21

[a] *m = mesophilic, t = thermophilic*

incineration taxes have been induced. Finally a favourable set of basic economic preconditions were established, according to which power companies are obliged to purchase electricity based on biogas at minimum prices. Danish plants obtained investment grants of 20-40 % of investment costs and production grants of DKK 0.27 per kWh electricity produced. In addition biogas is not energy taxed, and low interest rate, long-term (20 years) loans are provided.

5. ECONOMIC RESULTS

Table 12.2 shows actual economic results from the above mentioned 12 Danish centralised biogas plants. The analysis is based on the actual financial situation for each plant, which is a function of investment costs and grants, actual financing, and economic results so far. Economic results are measured as current income (total sales and gate fees minus operating costs) compared to a calculated minimum income target. Calculation of the minimum income target is, as mentioned, based on actual financial situation for each plant, and is as such not comparable among plants. But for each plant the minimum income level represents the break even situation, where debts can be served and current reinvestments be defrayed.

It appears from Table 12.2 that results have generally improved considerably over the years. In recent years most of the plants produced a current income at or above the break-even income level. A few plants however, faced various technical and other problems, and have therefore not yet, by the end of 1998, reached the calculated break-even income level.

Of course Table 12.2 does not tell the full story about production costs of the plants. Based on data from existing plants, transport and treatment costs were calculated for a fictive plant. The assumptions and results from this calculation are presented in Table 12.3.

In order to balance total costs of 62 DKK. per m^3 biomass treated, energy sales (and gate fees) must equal this amount. Calculations (Hjort-Gregersen 1998) show that, under Danish conditions, production costs may be balanced at an average biogas yield of approx. 34 m^3 biogas per m^3 biomass treated, at a biogas price of 1.81 DKK per m^3 biogas sold. If investment grants or gate fees (for the receipt of organic waste) are obtained, the demands on average biogas yield could be lower.

In order to achieve gas yields of this size it is necessary to add organic waste, which is then codigested with manure. It appears from Table 12.1 that all mentioned plants codigest considerable amounts of organic waste. The value of the waste, with respect to biogas production

potential, vary greatly among various waste types, depending on their contents of fatty compounds. Thus an unambiguous correlation between waste ratio and gas yields cannot be derived from Table 12.1.

Table 12.2. Development of current income (Hjort-Gregersen 1999) (1 DKK = 0.134 €)

1000 DKK	1994 or 1993/94	1995 or 1994/95	1996 or 1995/96	1997 or 1996/97	1998 or 1997/98	Break even. Income 1998 price level
Ribe						
Current income	2895	3230	3161	3298	3855	2600
Lintrup						
Current income	3622	3605	2639	3865	3457	3600
Lemvig						
Current income	3927	4642	3848	4444	4353	4200
Hodsager						
Current income	786	1106	1132	1195	1204	1200
Hashøj						
Current income	490	1502	1341	1882	1982	1500
Thorsø						
Current income	303	1482	1756	2023	2495	1800
Århus						
Current income	-	-	-3994	-2207	-1860	3500
Filskov						
Current income	-	742	1394	1526	1674	1500
Sinding/						
Studsgård	-	-	1762	2974	3327	6400
Current income						
Blåbjerg						
Current income	-	-	1676	3090	3809	3000
Snertinge						
Current income	-	-	-	1655	2180	2850
Blåhøj						
Current income	-	-	-	574	1845	1900

6. WASTE TREATMENT COSTS

Originally, the Danish centralised biogas concept was only designed for manure treatment. In Europe and worldwide, however, waste treatment is the main focus of interest in biogas and anaerobic digestion. It has become evident that the Danish concept is also well suited as a waste recycling facility, if a sanitation step included and monitoring procedures are adapted.

In (Hjort-Gregersen 1999) the waste treatment costs in a centralised biogas plant were calculated. In Danish centralised plants manure is as mentioned codigested with various organic waste types. From these

resources, approx. 30 m^3 biogas per m^3 biomass were assumed. At this production level, and an assumed price of DKK. 1.70 per m^3 biogas, energy sales amounted to DKK 51 per m^3 biomass. Table 12.4 shows the net production costs per m^3 biomass treated.

Table 12.3. Assumptions and total cost per m^3 biomass treated. Investment grants excluded (Hjort-Gregersen 1998) (1 DKK = 0.134 €)

Assumptions	
Per day biomass application	
Investments:	300 m^3
Biogas plant	
Vehicles	30 million DKK
Investment grants	3.6 million DKK
Depreciation rates	0
Technical installations	
Trucks	15-20 years
Tanks on trucks	7 years
Real interest rate	15 years
Utilisation of biogas	5 % p.a.
	Sold
Calculated total costs	DKK per m^3 biomass treated
Biomass transportation	
-operating costs	15
-capital costs	4
Anaerobic treatment	
-operating costs	17
-capital costs	26
Total costs	62

Table 12.4. Net production costs, no investment grants included (Hjort-Gregersen 1999)

(1 DKK = 0.134 €)	DKK per m^3 total biomass treated
Energy sales	51
Production costs	62
Deficit, net production costs	-11

It appears that net treatment costs, represented by the calculated deficit, amounts to DKK 11 per m^3 biomass treated. If the gas yield or the biogas price were higher, net treatment cost would be lower, and *vice versa.*

The deficit could also be defined as the waste treatment costs, which would then be the net fee for a company who has a waste problem. At a waste ratio of 20 %, net waste treatment costs are DKK 11/20* 100 = DKK 55 per m^3 waste. These treatment costs should be compared to alternative waste disposal options. In Denmark organic waste deposition in

landfills is no longer allowed. Instead waste must be recycled or incinerated. Consequently, waste producers face treatment costs for composting or incineration of DKK 200 – 400 per m^3 waste. If incinerated, additional DKK 210- 269 waste deposit tax is imposed. Normally, Danish centralised plants charge 50 – 100 DKK pr. m^3 waste they receive at the plant. From waste producers point of view this 'gate fee' is favourable compared to alternative waste disposal options.

7. DERIVED ECONOMIC BENEFITS FOR INVOLVED FARMERS

Farmers were the main driving force in the development of centralised biogas plants in Denmark. In normal situations they do not withdraw a profit from the biogas companies. Instead they gain a number of derived economic benefits as a result of the biogas plant operation.

Over the last decades livestock farming, in Denmark as well as in other countries, has been increasingly concentrated. As the environmental impacts of intensive livestock farming have been increasingly apparent, legislation on livestock production, manure handling and application has been gradually strengthened. Some of these rules are included in the so-called 'legislative push' mentioned previously. Originally farmers regarded the new rules as quite rigorous, as increased costs were thereby imposed on livestock production. Now it is generally conceived that the rules were technically well founded.

According to law livestock farmers must control certain manure storage capacity. When this requirement was imposed the majority of Danish livestock farmers faced considerable investments in slurry storage facilities. However, in some areas, centralised biogas plants were established, and provided the needed storage capacity. Consequently, farmers gained benefits in the form of *cost savings from manure storage* (Hjort-Gregersen 1993).

The so-called 'harmony rules' lay down maximum levels to the manure amounts applicable per land unit. Livestock producers, who do not own sufficient land themselves, must make agreements with crop producers concerning slurry transfer. In some cases, when agreements are not obtainable, farmers are forced to rent or buy land, which is not necessarily recommendable from an economic point of view. In addition, the transportation distance to these fields may be considerable, and manure transportation costs significant. When planning a centralised biogas plant, much care is taken in suitable location of slurry storage facilities near the fields, where the digested manure is end-used as a fertiliser. The

transportation system is operated and paid for by the biogas plant. The digested manure is, by the farmer's decision, returned either to the farm or to a so-called decentralised storage tank somewhere else. Hereby the farmer benefits from *cost savings in manure transportation* (Hjort-Gregersen 1993).

In a centralised biogas plant pig slurry is mixed with cattle slurry and various types of organic waste. Danish experience show that the slurry mix, as a fertiliser, is more advantageous than conventional slurry. This is due to the additional nutrients from often relatively concentrated organic waste. But also composition of the slurry mix makes a difference. Pig slurry often contains a phosphorus surplus but a potassium deficit for a typical crop rotation on pig farms. Cattle slurry, on the contrary, often contains a potassium surplus but a phosphorus deficit for typical crop rotations on cattle farms. Consequently, the digested slurry mix is more valuable for both pig and cattle farms than their respective conventional slurry. A higher nutrient utilisation is achieved, and farmers gain benefits from *cost savings in fertiliser purchase* (Hjort-Gregersen 1993).

Naturally the size of the derived economic benefits are dependent on the actual situation on each farm. Calculations in Hjort-Gregersen (1993) show that farmers may gain an average of 5 DKK. per m^3 slurry supplied to the biogas plant. The benefits mainly derive from cost savings in slurry storage and fertiliser purchase. In addition, less odour nuisances appear from digested compared to conventional slurry. This is very much appreciated by farmers, who otherwise often become increasingly unpopular in times of slurry spreading.

8. PERSPECTIVES ON A NATIONAL AND EUROPEAN LEVEL

In Denmark, as well as in many other European countries, considerable potential for biogas production exists. In 1998 a total of 1.1 million tonnes of manure and 0.2 million tonnes of organic waste were applied to centralised biogas plants in Denmark. These biomass amounts account for approximately 2.5 per cent of total manure, and approximately 8 per cent of organic waste available in Denmark. It appears that manure and organic waste represents a tremendous potential for biogas production in Denmark. Similar potentials can be found in other European countries, which appears from Table 12.4. It appears that many EU countries have considerable potentials for biogas production. Particularly those with widespread livestock production, as animal manure accounts for the vast majority of biogas production potential in Europe. Based on 1993 data, realisation of

the Danish biogas production potential would account for approximately 5 per cent of final energy consumption in Denmark (Eurostat 2000). The EU 15 biogas production potential would, if realised, account for approximately 2 per cent of EU 15 final energy consumption (Eurostat 2000). However, the scheduled potentials are only theoretical, as it is neither practically nor economically viable to utilise all manure and waste resources for biogas production. Before the realisation of each plant, a number of preconditions must be fulfilled, which has often been the case in Denmark, but will not necessarily be true for other European countries.

Table 12.4. Digestible biomass resources and potential biogas-energy production in 15 EU countries, 1993 data (Al Saedi and Holm-Nielsen 1997)

	Animal manure Million tonnes 1993	Organic waste from households and industry Million tonnes 1993	Biogas production potential PJ in 1993
Austria	32	4.1	22
Belgium	49	3.0	32
Denmark	44	2.5	32
Finland	17	1.3	11
France	238	13.9	154
Germany	218	16.6	143
Greece	9	2.4	7
Ireland	69	1.5	43
Italy	95	17	68
Luxembourg	2	0.1	1
The Netherlands	77	3.8	49
Portugal	20	2.0	13
Spain	89	19.2	66
Sweden	24	2.3	16
United Kingdom	141	14.4	95
Total EU 15	1124	104.1	752

9. CONCLUSIONS

Considerable efforts in developing the centralised biogas concept in Denmark have been carried out over the last 15 years. As a result, today 20 plants are in operation. Its has been demonstrated how centralised biogas plants, as integrated energy production, waste treatment and nutrient redistribution facilities, make a valuable contribution to the solution of a range of problems in the fields of environment, agriculture and energy.

Gradually improved economic results lead to a situation where most of the plants today find themselves in an acceptable economic situation, as operation stability has been improved significantly over the years, and satisfactory levels of biogas production is achieved by most plants.

Treatment of organic waste in centralised biogas plants has proven to be an economically favourable and environmentally advantageous option, in waste treatment and recycling.

Farmers involved in centralised biogas plants do not withdraw a profit from the biogas companies. Instead they gain derived economic benefits in the form of cost savings in manure storage and transportation, and in fertiliser purchase.

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Part V

Scenarios and policies for sustainable energy

Chapter 13

CAN ORGANIC FARMING HELP TO REDUCE NATIONAL ENERGY CONSUMPTION AND EMISSIONS OF GREENHOUSE GASSES IN DENMARK?

Tommy Dalgaard, Niels Halberg and Jes Fenger

1. INTRODUCTION

Methods to investigate whether organic farming might help to reduce energy consumption and greenhouse gas emissions are needed. The aim of this study is for the first to present an upscaling procedure, where an existing farm level energy consumption model, in combination with the Intergovernmental Panel on Climate Change's guidelines, is used to calculate agricultural energy consumption and greenhouse gas emissions on the national level. Secondly, this procedure is used to simulate scenarios for conversion to organic farming in Denmark.

Three scenarios for conversion to organic farming with the present crop yield and an expected improved future crop yield are compared to the 1996-situation in Denmark, where conventional farming dominates. In all scenarios, fossil energy use and emissions of the three major agricultural greenhouse gases carbon dioxide, methane and nitrous oxide are reduced.

The first aim of this chapter is to present an upscaling procedure, where an existing farm level model for energy use (Dalgaard *et al.* 2001), in combination with existing methods to calculate agricultural emissions of greenhouse gasses (IPCC 2000), is used to calculate national level energy consumption and greenhouse gas emissions. The second aim is to use this procedure to simulate three scenarios for conversion to 100% organic farming in Denmark and by comparison to the 1996 situation to answer the question 'Can organic farming help to reduce national energy consumption and emissions of greenhouse gasses in Denmark?'

There are three main reasons to limit the use of fossil energy. First, fossil energy is a limited resource which, as far as possible, should be conserved for the coming generations (Brown *et al.* 1998). Second,

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combustion of fossil energy leads to classical pollution via compounds of sulphur and nitrogen, which damage the environment via acidification, eutrophication etc. (Illerup *et al.* 1999). Finally, combustion results in emissions of the greenhouse gas carbon dioxide (CO_2). This gas is responsible for most of the anthopogenic changes in the earth-atmosphere energy balance, which may lead to global climate changes (IPCC 1997).

As a result of the Rio-conference in 1992 and the Kyoto Protocol in 1997, industrialised countries are committed to reduce their greenhouse gas emissions. Here not only carbon dioxide from energy use counts but also nitrous oxide and methane, which to a large extent are of organic origin. One method to reduce greenhouse gas emissions is to change agricultural production. In Denmark, the agricultural sector currently is responsible for about 12% of the total contribution to the greenhouse effect (Fenger *et al.* 1990), and changes in agricultural greenhouse gas emissions therefore matters. Farm level studies have identified large potentials for reductions of the fossil energy use from conversion to organic farming (Dalgaard *et al.* 2001). However, there are no well-described national level methods to calculate consequences for energy use and greenhouse gas emissions following conversion to organic farming (Halberg *et al.* 2000). Moreover, the existing reference manuals for calculation of national emissions of greenhouse gases (IPCC 1997, 2000) give some guidelines, but do not distinguish CO_2-emissions from agriculture from emissions from other sectors, and cannot be readily adapted to investigate scenarios for changes in agricultural production systems. However, the reference manuals can more readily be used for the calculation of emissions of the two other important greenhouse gases relating to agricultural production; nitrous oxide (N_2O) and methane (CH_4).

The present chapter focuses on national scenario calculations of energy consumption and greenhouse gas emissions based on agronomic model calculations. However, the results must be seen in a broader sustainability context, and can for instance be combined with economic calculations where the costs and benefits in relation to these externalities are estimated. The possibilities for such inter-disciplinary interactions are discussed at the end of this chapter.

2. MATERIALS AND METHODS

2.1 Scenarios for 100% conversion to organic farming in Denmark

In 1998, the Danish Government requested an inter-disciplinary review of the consequences of phasing out pesticides. One of the resulting reports

(Bichel Committee 1999) concerned conversion to 100% organic farming in Denmark and the resulting ban on the use of both pesticides and synthetic fertilisers. In this study, the following three theoretical scenarios for 100% conversion to organic farming within a thirty-year time horizon are considered (Alrøe *et al.* 1998):

- Full national self-sufficiency with fodder (*i.e.* no import). This particularly limits the pig production, because it was assumed that the total Danish milk quota would still be produced after conversion.
- 15% import of fodder for ruminants and 25% import for non-ruminants. Here the pig production is limited too, but less than in scenario A.
- The same level of animal production after conversion as in 1996 (unlimited import of fodder).

In this chapter, crop production on the 2.7×10^6 ha agricultural area of Denmark is simplified to consist of grass/clover, cereals, row crops and permanent grass. For each crop type, the yield is estimated in SFU's[1] for the present practice on organic Danish farms (Halberg and Kristensen 1997), and for an expected improved future practice (Table 13.1).

Table13.1. Estimated Danish crop yields (102 SFU/ha), and in brackets the crop distribution on the agricultural area (106 ha). After Alrøe et al. (1998)

	Conventional agriculture 1996	Organic Scenarios A, B and C present yield	improved yield
Grass/clover	65 (0.3)	52 (1.0)	57 (1.0)
Cereals	50 (1.6)	34 (1.3)	39 (1.3)
Row Crops	104 (0.4)	97 (0.2)	97 (0.2)
Permanent Grass	20 (0.4)	18 (0.2)	18 (0.2)

For example, the potential for yield improvements in organic cereals and grass/clover are expected to be 15% and 10%. From this the corresponding livestock production in LSU's[2], and fodder import is estimated (Table 13.2).

Table 13.2. Total Danish crop production, fodder import and animal production

		Conventional agriculture 1996	Organic Scenarios present (improved) crop yields A	B	C
Crop production	10^9 SFU	15	12 (13)	12 (13)	12 (13)
Fodder import	10^9 SFU	4	0 (0)	2 (3)	4 (3)
Livestock units	10^6 LSU	2.3	1.7 (1.7)	2.1 (2.3)	2.4 (2.4)

2.2 Simulation of fossil energy use

For each crop type the average, national fossil energy use is simulated with Dalgaard *et al.*'s (2001) model (Table 13.3 and 13.4). This model can simulate fossil energy use for the most common crops in Denmark for different management practices, transport distances, soil types etc. The model includes both direct and indirect (embedded) energy use and a set of standard values for energy use in keeping livestock. In this chapter, average national energy use for the crop types is calculated as weighted averages for the crops grown on loamy soil, sandy soil, and irrigated sandy soil. The distribution of Danish soils by area is 39% loamy soils, 10% irrigated soils, and 51% non-irrigated sandy soils. Grass/clover is defined as 50% grass/clover pasture and 50% grass/clover silage.

Table 13.3. Average Danish energy use for conventionally grown crop types

10^6 J/ha	Grass/clover	Cereals	Row Crops	Perm. grass
Oil[a]	3.1	4.5	13.2	0.8
Electricity[b]	0.8	0.9	0.4	0.0
Fertilisers[c]	10.3	5.9	4.3	0.7
Machinery	1.0	1.4	4.0	0.3
Total	15.2	12.7	21.9	1.8

[a] Diesel, petrol, lubricants etc., incl. refining and distribution, [b] Irrigation and drying, [c] Fertilisers, pesticides and lime.

Cereals are defined as 50% winter cereals and 50% spring cereals, including energy use for both grain and straw harvest. Row crops are defined as fodder beets, and permanent grassland is defined as grass/clover pasture on non-irrigated sandy soil. For comparison, the metabolisable energy in the produced crops can be calculated using norms (Strudsholm *et al.* 1997), and compared to the fossil energy use.

Table 13.4. Average, Danish energy use for organic grown crop types with present yields, and with improved yields expected in the future (in brackets)

10^6 J/ha	Grass/clover	Cereals	Row Crops	Perm. grass
Oil[a]	2.4 (2.6)	4.3 (4.3)	11.3 (11.6)	0.8 (0.8)
Electricity[b]	0.8 (0.8)	0.7 (0.8)	0.5 (0.5)	0.0 (0.0)
Fertilisers[c]	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Machinery	0.7 (0.8)	1.3 (1.3)	3.4 (3.5)	0.3 (0.3)
Total	4.0 (4.2)	6.3 (6.4)	15.2 (15.6)	1.1 (1.1)

[a] Diesel, gasoline, lubricants etc., incl. refining and distribution, [b] Irrigation and drying, [c] Fertilisers, pesticides and lime.

Given the energy use for crop production, the number of animals produced, and the needed fodder import, the total national energy use can be estimated (Dalgaard 2000). For the 1996-situation, the calculated energy

use for each type of energy source (SI) can be compared with the energy use according to official statistics (ST), and a correction factor (CF=ST/SI) can be calculated (Table 13.8). These CF-values are then used to correct the simulated values of energy use in the scenarios for conversion to organic farming.

Finally, the net energy production from crop residues and biogas is added to get the national agricultural energy balance. For the 1996-situation, production values from national statistics are used (13.7 PJ from straw combustion, and 0.5 PJ biogas from slurry, Danish Energy Agency 1997). In the organic scenarios, it is assumed that no energy production takes place, because all the straw is needed for deep bedding in the stables, and mining of carbon in the form of biogas from slurry is perceived undesirable.

2.3 IPCC's greenhouse gas inventories

The CO_2-emission for each fossil fuel is estimated from Equation 13.1, where C is % carbon in the fuel, M_{CO2} is the molecular weight of $CO_2 = 44$ g/mole, B_t is the lower combustion value for the fuel, and M_c is the molecular weight of C= 12 g/mole. From this, CO_2-emission factors for the most common fuels and input factors in agriculture are calculated (Table 13.5). The CO_2-emission from biofuels is set to zero, and emissions related to indirect energy input like machinery and fertilisers are set to the emission from the energy source, from which these are primarily produced (The European Commission 1997).

$$CO_2\text{-emission} = \frac{C \times M_{CO2} \times 10}{B_t \times M_c} \qquad (13.1)$$

Table 13.5. Examples of CO_2-emission factors

	CO_2-emission factor (kg $CO_2/10^9$J)
Coal	95.0
Diesel oil	74.0
Natural gas	56.9
Biofuels (biogas and straw)	0.0
Electricity	95.0
Machinery	95.0
Synthetic fertilisers	56.9
Concentrates	74.0

All the CH_4-emissions from Danish agriculture are presumed to come from livestock. For each animal type, the CH_4-emission is calculated

as the sum of the standard emissions (EF)[3] from the animal and the related manure production (Equation 13.2, IPCC 1997).

$$CH_4\text{-emission} = EF_{animal} + EF_{manure} \quad (13.2)$$

Finally, the N_2O-emission is calculated as the sum of direct and indirect emissions (Equations 13.3-13.5). The emission factors EF_1 = 0.0125 kg N_2O-N/kg N-input is for the direct emission from the soil, EF_2 = 5 kg N_2O-N/ha/yr is for the mineralisation of organic soils, and EF_3 = 0.0114 kg N_2O-N/kg N is for animal production facilities (stables and pastures). F_{OS} is the area of organic soils (histosols) in rotation. F_{AW} is manure-N handled, corrected for non N_2O-N-emissions, in the form of *e.g.* NH_3 or NO_x, and the N produced at pasture. F_{AP} is manure-N ex animal. F_{BN} is N fixed from the atmosphere by legumes (kg N/yr). F_{CR} is crop residues returned to the soil (kg N/yr). F_{SN} is the synthetic fertiliser-N (kg N/yr) used. M_N and M_{N2O} are the molecular weights for nitrogen and nitrous oxide. The indirect N_2O-emission includes N_2O produced from the atmospheric deposition of NO_2 and NH_3 volatilised from spread fertilisers (N_{GAS}), and N_2O produced from the N, which is leached from agricultural soils (N_{LEACH}). EF_4 = 0,01 kg N_2O/N-gas and EF_5 = 0.025 kg N_2O-N/N-leached are standard emission factors (IPCC 1997). Both CH_4 and N_2O emissions are converted to CO_2-equivalents by multiplication of their global warming potentials for a 100 year time-horizon: 21 and 310 (Fenger and Kilde 1994).

$$N_2O\text{-emission} = N_2O_{direct} + N_2O_{indirect} \quad (13.3)$$

$$N_2O_{direct} = \frac{2 \times M_N}{M_{N2O}} \times \begin{bmatrix} \left(\left(F_{SN} + F_{AW} + F_{BN} + F_{CR} \right) \times EF_1 \right) \\ + F_{OS} \times EF_2 + F_{AP} \times EF_3 \end{bmatrix} \quad (13.4)$$

$$N_2O_{indirect} = \frac{2 \times M_N}{M_{N2O}} \times \left(N_{GAS} \times EF_4 + N_{LEACH} \times EF_5 \right) \quad (13.5)$$

3. RESULTS

3.1 Fossil energy use

The national 1996-energy use for the defined crop and animal types are simulated and distributed over energy sources (Table 13.6 and 13.7). Thereafter, the simulated values (SI) are, in line with Dalgaard *et al.* 2001,

compared to statistics (ST), and a correction factor (CF=ST/SI) for each energy source is calculated (Table 13.8).

Table 13.6. Calculated Danish energy use (10^{15} J) for the 1996 crop production

	Grass/clover	Cereals	Fodder Beet	Perm. grass	Total
Oil	1.0	8.2	6.8	0.4	16.3
Electricity	0.2	1.4	0.2	0.0	1.8
Fertilisers [a]	2.8	9.5	1.9	0.3	14.5
Machinery	0.3	2.2	1.8	0.1	4.4
Total	4.2	21.4	10.7	0.7	37.0

[a] *Incl. pesticides.*

Table 13.7. Calculated Danish energy use (10^{15} J) for the 1996 animal production

	Cattle	Pigs and Poultry	Total
Electricity in stables	7.3	3.3	10.7
Oil for heating stables	0.0	1.7	1.7
Buildings, inventory etc.	3.2	2.5	5.7
Fodder Import	7.0	13.0	20.0
Own fodder production [a]	16.2	14.8	30.0
Total	33.8	35.3	69.0

[a] *The part of energy for crop production (Table 13.6), which is not exported.*

Table 13.8. Simulated total energy use for agricultural production in Denmark 1996 compared to national statistics (Dalgaard et al. 2001)

	PJ fossil energy		Correction-factor
	Simulated (SI)	Statistics (ST)[a]	(CF=ST/SI)
Direct energy use			
Fuels	18.0	19.3	1.1
Electricity	12.5	12.7	1.0
Indirect energy use			
Fertilisers, pesticides etc.	14.5	13.9	1.0
Machinery	4.4	4.6	1.1
Buildings	5.7	6.3	1.1
Import of fodder	20.0	20.0	1.0
Total energy use	75.1	76.8	

The same procedure is used to calculate the energy use for crop and livestock production in the organic scenarios. However, since no statistics are available for the future scenarios, the CF-factors calculated for the 1996-situation (Table 13.8) are used to correct the SI-values of the organic scenarios. From these figures, total national agricultural energy balances are produced (Table 13.9). In these balances, energy use for production of fodder is accounted for under crop production.

Table 13.9. Total Danish agricultural energy balance (10^{15} J) for the 1996-situation and for the three organic scenarios with respectively the present and (in parenthesis) improved yields

	Danish agriculture 1996	Organic Scenarios present (improved) crop yields A	B	C
Crop production	38	18 (18)	18 (18)	18 (18)
Livestock production	39	13 (14)	28 (31)	40 (34)
Total	77	31 (32)	45 (50)	57 (53)
Energy production	14	0 (0)	0 (0)	0 (0)
Net energy use	63	31 (32)	45 (50)	57 (53)

The results show that the total net energy use in all the organic scenarios would be lower than the 1996-energy use. However, the energy use should also be compared to the production, which is higher in the 1996-situation (Table 13.2). Finally, energy efficiencies, expressed as the fossil energy use per produced fodder and livestock unit, are calculated (Table 13.10).

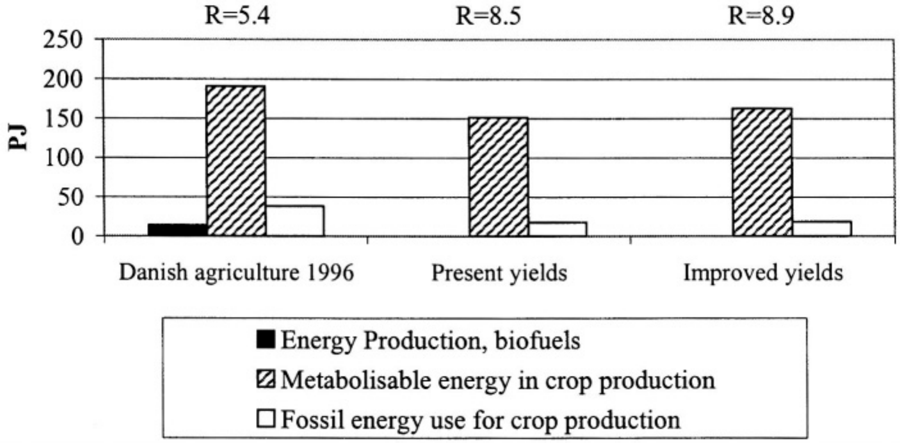

Figure 13.1. The bio-fuel energy and the metabolisable energy in the crops produced compared to the fossil energy use for crop production in 1996, and in the two organic scenarios with the same animal production (Scenario C: unlimited fodder import). R is the ratio between energy production and energy use. (1 PJ=10^{15} J)

Table 13.10. Average Danish energy use per produced fodder- and livestock unit (1 MJ=10^6 J)

	Danish agriculture 1996	Organic Scenarios present (improved) crop yields A	B	C
Crop prod. (MJ/SFU)	2.5	1.5 (1.4)	1.5 (1.4)	1.5 (1.4)
Livestock prod. (MJ/LSU)	30	18 (18)	21 (21)	24 (21)

3.2 Emissions of greenhouse gases

Emission of CO_2 is calculated from the accounted energy use and does not include storage in soils or emissions from soils and agricultural crop burning. The reason for this is that these effects are too uncertain to include in the scenarios, and that conversion to organic farming will only result in minor changes (Dalgaard *et al.* 2000). The CH_4-emission is calculated from the number of animals (Table 13.11) and N_2O-emission from estimated direct and indirect contributions (Table 13.12).

Table 13.11. Example: calculation of the 1996 CH_4-emission

		CH_4-emission (10^9 kg)		
	10^5 animals	from animals	from manure	Total
Dairy cows	8.3	99	12	111
Heifers	9.1	44	5	49
Bullocks	5.8	28	3	31
Sows	10.1	2	3	5
Other pigs	52.8	8	16	24
Hens	55.0	0	1	1
Total		180	40	220

Table 13.12. Example: calculation of the 1996 N_2O-emission

		Emission (10^6 kg N yr^{-1})	Total (10^6 kg N_2O)
Direct emission(N_2O_{direct})			
Synthetic nitrogen	F_{SN}	292	5.7
Animal waste handling	F_{AW}	131	2.6
Animal production	F_{AP}	222	4.0
Legumenous fixations	F_{BN}	138	2.7
Crop residues	F_{CR}	331	6.5
Organic soils (ha area)	F_{OS}	18440	0.1
Indirect emission ($N_2O_{indirect}$)			
Deposited gas from fertilisers	N_{GAS}	103	1.6
Leaching	N_{LEACH}	198	7.8
Total			31.0

Subsequently, the emissions of greenhouse gases can be converted to CO_2-equivalents (Figure 13.2). The methane emissions are not significantly reduced in the organic scenarios because the productions of ruminants are sustained. In contrast, the nitrous oxide emissions are reduced, primarily because no mineral fertilisers are used in the scenarios for conversion to organic farming, and because emissions from crop residues and N-leaching decay.

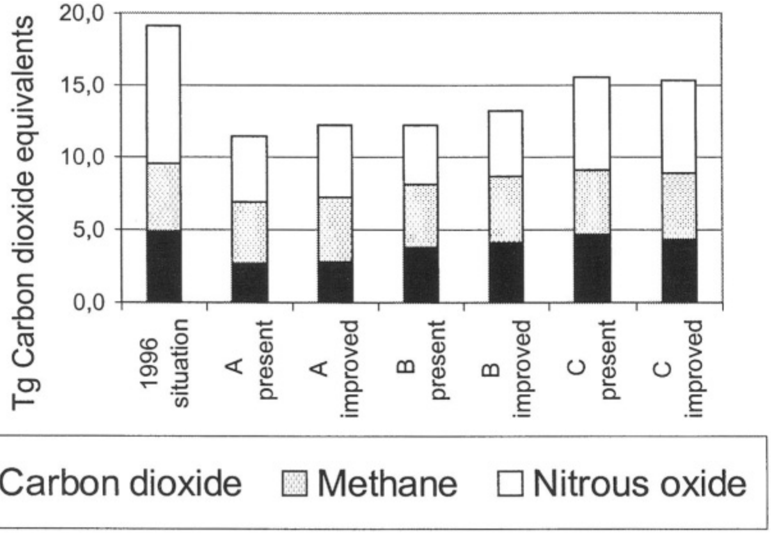

Figure 13.2. Total national agricultural emissions of greenhouse gases (1 Tg=10^9kg)

4. DISCUSSION

The calculations show that a conversion to 100% organic farming in Denmark may result in a reduced fossil energy use and reduced emissions of the three most important greenhouse gases. However, the vegetable and animal production would also be lower in the organic scenarios. Therefore, for example, the total energy use for crop production would be reduced by 52-53%, while the energy use per fodder unit would be reduced by only 40-44%.

The presented benefits in the form of lower energy consumption and greenhouse gas emissions from conversion to organic farming must be compared to the costs of such conversion. The macro-economic consequences of conversion to 100% organic farming is extremely difficult to estimate, partly because of the expected major changes in marked prices following the much higher market share of organic products after full conversion and partly because of the uncertainties in estimation of the costs in organic compared to conventional production. If the organic product prices after 100% conversion would equal the present, conventional product prices, Jacobsen and Frandsen (1999) estimated a reduction in the total Danish Gross Domestic Product of 1-3% and a reduction of the private consumption between 2-5%. However, if consumer preferences

result in higher future prices on organic products the overall costs for the society would be lower.

In the 1996-situation, there is a potential to double the production of bio-energy in the form of straw and biogas (Dalgaard *et al.* 2000). This potential is not as large in the organic scenarios, where straw production is lower, and more straw is needed for the deep bedding stables, required for animal welfare reasons. If the conventional biomass potential was fully utilised, another 14×10^{15} J bioenergy could be produced. If this energy was deducted from the 1996 energy use no energy would be saved by conversion to 100% organic farming. Furthermore, there was an export of 2×10^{9} kg grain in the 1996-situation. If these cereals were burned in power plants for heat and electricity, a gross energy production of about 30×10^{15} J may be achieved. In this situation, the conventional farming of 1996 has a more positive energy balance than any of the scenarios for conversion to organic farming. However, there are many unanswered questions concerning the possibilities for combined food energy systems (Kuemmel *et al.* 1998), which may change the conclusions of this chapter. Further investigations within this area are therefore recommended.

The comparison of simulated energy use with official statistics showed a good prediction of the 1996-situation. The calculated CFs from 1996 were therefore also used to correct the simulation results in the organic scenarios. This linear scaling procedure was the best procedure within the limits of the present work, but future work can possibly improve the methods for upscaling and the possibility to test simulated, national scale results considerably. One reason why the 'true' CF for the organic scenarios might differ from the 1996-CF is the different field size distribution on the organic farms. This becomes important because the known non-linear relation between field size and energy use (Nielsen and Sørensen 1994) is not included in Dalgaard *et al.*'s (2001) model. Another reason is that the marked for organic products is effected by the scale to which the conversion happens. Conversion of one farm will not effect the marked but a 100% conversion of the whole country will, as discussed above, change both the prices of agricultural products and the demand for fodder and energy dramatically (Jacobsen and Frandsen 1999). To assess such scale effects, simple aritmethic aggregation might not be sufficient. Consequently, new procedures to scale up farm level information on energy use and emissions of greenhouse gases to the regional and national level are needed.

In this study, the default IPCC (1997) methodology for calculation of methane and nitrous oxide emissions is applied to scenarios where the Danish agricultural production was described in highly aggregated livestock and crop type groups. However, the calculated emissions in the

1996-situation were similar to the values of a more detailed study of emissions from Danish agriculture in 1995 (Andersen 1999). Consequently, it seems that our scenario resolution is sufficient to get reliable results for greenhouse gas emissions.

The total greenhouse gas emissions are not surprisingly lowest in the scenario with the highest fodder self-sufficiency and the lowest animal production (A), while the highest emissions found are where the animal production and the fodder import is high (C). In the scenarios A and B, the greenhouse gas emissions are increased when the crop yields are improved, while the opposite is the case in scenario C. The cause for this is, that the animal production in scenario A and B are limited by the total crop yield. Therefore, higher yields lead to a higher animal production and higher greenhouse gas emission. On the contrary, in scenario C, the animal production is not limited by the crop yield, because import of fodder sustains an animal production equal to the one in 1996. Therefore, higher yields here leads to a lower fodder import, which lower the total greenhouse gas emissions. To validate whether this reverse relationship may be caused by a too high energy cost for imported fodder assumed in Dalgaard *et al.*'s (2001) model, a sensitivity analysis is carried out. If for instance the energy cost for imported fodder is reduced by 25%, the difference between the greenhouse gas emissions for present and improved crop yields in scenario C is reduced by 0.1 Tg carbon dioxide equivalents. However, this reduction is less than the difference described above, and the reduction in total greenhouse gas emissions by increasing the yields do not seem to be caused only by an overestimated energy cost of imported fodder. Similarly, the present scenarios could be used as a basis for economic sensitivity analysis, and the role of prices in input and output choice both on the farm level and with the society as a whole could be analysed.

5. CONCLUSIONS

The presented method is useful to calculate national energy consumption and emissions of greenhouse gasses from both conventional and organic farming. However, the method to scale up energy consumption from an existing farm level model to the national level was only possible to validate for conventional farming. Future work on procedures to estimate consequences of conversion to organic farming on larger scales than the farm is therefore needed.

Results showed that CO_2 from agricultural energy consumption is responsible for about 1/4 of the greenhouse gas emissions from both

conventional and organic agricultural production. In the scenarios for conversion to organic farming, the N_2O-emission is particularly reduced, partly because of lower nitrogen losses (Dalgaard *et al.* 1998). Also for the other two major greenhouse gases, a significant reduction is expected following organic conversion. The net greenhouse gas emission from agriculture may in the future be lowered via increased bio-energy production, and a large unused potential for such bio-energy production is present in conventional agriculture.

In conclusion, conversion to organic farming might help to reduce energy consumption and emissions of greenhouse gasses in Denmark, but for policy analysis these reductions must be evaluated also with other criteria for a sustainable future agricultural production.

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NOTES

[1] Scandinavian Fodder Unit (SFU)= 12.5 MJ barley equivalent, metabolisable energy
[2] Livestock Unit (LSU) corresponded in 1996 to 1 cow of large breed, 3 sows or 30 porkers produced
[3] Standard EF-values for cool regions (mean annual temperature <15°C) are used.

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Chapter 14

ON RENEWABLE ENERGY IN RURAL CHINA

Huang Liming and Ekko C. van Ierland

1. INTRODUCTION

This chapter analyzes the trend of renewable energy in rural China. It provides projections of renewable energy for the year 2020, based on a straightforward application of income elasticity analysis. We find that with the rapid development of China's rural economy and requirement for protection of the environment, the scope for renewable energy will increase significantly. The chapter concludes by discussing a number of problems for further development of sustainable energy in rural China and suggests international cooperation to solve some of these problems.

The development of sustainable energy in the rural areas of China is fundamental to its rural economy, and the improvement of people's living standards. Over 860 million people are living in rural China, of whom 72 million have no electricity (International Statistical Yearbook 1998; Battelle Memorial Institute 1998; China Government 2000a). There are 70 million people living in poverty (China Government 2000a). It is of great significance to develop and apply renewable energy in line with the local conditions. On the one hand, it can provide electricity for the remote northwest areas and coastal islands that are at present without or short of electricity. On the other hand, it can help these areas to shake off poverty. Although rural China has abundant energy resources and has achieved remarkable progress in the development of renewable energy, its existing energy structure is still based on non-renewable fossil energy. This inevitably leads to the continuing depletion of energy resources and emissions of pollutants and greenhouse gases.

This chapter analyzes the present situation and future development of sustainable energy in rural China. The current trend of rural energy consumption and a number of problems for further development of sustainable energy in rural China are discussed. Furthermore, this chapter shows that international cooperation may contribute to a solution for this problem.

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The remainder of this chapter is organized as follows. In Section 2 we analyze the present situation of sustainable energy resources and development. Section 3 deals with the structure of energy demand in rural China. In Section 4 we show some projections for renewable energy in rural China, based on some alternative assumptions on income elasticities for renewable energy. In Section 5 we discuss a number of problems for further development of sustainable energy and the potential role of international cooperation for the development of renewable energy.

2. THE PRESENT SITUATION OF RENEWABLE ENERGY

China has abundant renewable energy potential and the resources are mainly found in rural areas. The hydropower potential is 378 million kilowatts, of which 11 percent has been developed. Biomass energy potential, including firewood stalks and other kinds of organic wastes, equals 260 Mtce[2]. In China, there are about 6 million square kilometers of land on which the level of total yearly solar radiation exceeds 600,000 Joules per square centimeter, which offers scope for solar energy. The potential of wind energy is 1.6 billion kilowatts, of which about 10 percent can be developed. Geothermal resources need further exploration. So far, the reserves of geothermal energy resources explored equal the equivalent of about 462.6 billion tons of standard coal (China Government 2000b). In addition to extending supply of sustainable energy there is also scope for energy efficiency improvement.

Progress has been made in the development of renewable energy in rural China in the recent past. In 1995, renewable energy production reached 2.6 Mtce, excluding hydropower (25.1 Mtce) and traditional biomass (19.9 Mtce), see Table 14.1.

There are 5.25 million methane-generating pits in China, mainly in rural areas (China Government 2000b), where methane is produced below the soil surface. Methane production dominated renewable energy production in rural China, accounting for 51.5 percent of total renewable energy production 1995 (Table 14.1). Comprehensive utilization of methane occurs in ecological agriculture in rural areas. This reflects the availability of methane resources in rural areas and the comparative advantage of methane production in rural China.

Solar energy in rural China includes two categories: the utilization of solar heat and the use of solar-cells. Solar heat includes solar energy water heaters, solar stoves, passive-type solar houses and solar energy dryers. Solar-cells are used in telecommunication systems and in the

remote (no-electricity) areas, and their sales volume was about 1.1 Megawatts per year (China Government 2000b).

Total installed capacity of wind power is up to 26,000 kilowatts. Since the 1980s, 50 to 200 watt micro wind power generators have successfully been developed and put into mass production. At present, there are about 120,000 sets of such generators operating in the grasslands of pastoral areas in Neil Mongol, Xinjiang, Qinghai and other coastal areas where there is no power grid (China Government 2000b).

In rural China, the development of geothermal resources also plays a role. By 1995, rural geothermal energy production reached 0.85 Mtce, accounting for 15.3 percent of total renewable energy production in rural China (Table 14.1).

Table 14.1. China's rural renewable energy production in 1995

Type of renewable energy source	Share in total renewable energy supply (%)	Amount produced (Mtce)
Methane	51.5	1.34
Solar	22.3	0.58
Wind energy	10.7	0.28
Geothermal energy	15.3	0.40
Total	100.0	2.60

Source: Li and Zhang (1998) and China Statistical Yearbook (1997)

Although China's rural areas have abundant potential of renewable energy resources and have achieved remarkable progress in the development of renewable energy, production of renewable energy is still in its infancy. Renewable energy consumption accounts for about 0.7% of total consumption of rural energy (Table 14.2). There is a huge potential for China to develop rural renewable energy because of the abundant potential of renewable energy resources in rural China and achievements obtained in the development of renewable energy in other countries.

3. ENERGY DEMAND IN RURAL CHINA

Energy consumption in rural China has a unique structure. The energy consumption is divided into two components, one for productive economic activities and one for rural household's living. The energy used for economic activities (mainly coal, electricity and oil) is commercial energy. Most of the energy used for household's living is non-commercial energy obtained from traditional biomass (firewood and straw). It accounts for 67 percent of energy consumption for living and 58 percent of total energy

consumption in rural China in 1995. Below, we analyze the developments of rural commercial energy demand and non-commercial energy demand.

Table 14.2. Rural energy consumption by fuel type in China in 1995

Fuel type	Amount consumed (Mtce)	Rural energy consumption by share (%)
Coal	103.0	27.3
Electricity	53.4	14.0
Oil	19.0	5.0
Traditional biomass (firewood and straw)	199.0	52.0
Other renewable energy	2.6	0.7
Total	378.0	100.0

Note: Renewable energy in this table includes marsh gas, solar, wind energy and geothermal energy. Source: China Statistical Yearbook (1996-1998); Li and Zhang (1998), own calculation

Rural commercial energy demand

Economic growth is the main factor driving demand for commercial energy. Since the policy of reform and opening up was adopted in 1978, Chinese agricultural income and commercial energy consumption for agriculture has grown rapidly. Between 1980 and 1995, the real gross output of agriculture rose from 117.2 billion Yuan to 241.6 billion Yuan, while commercial energy consumption for agriculture grew from 34.7 Mtce to 55.0 Mtce (see Table 14.3). Between 1980 and 1995, total energy consumption in agriculture grew by 3.1 percent per year, whereas agricultural income rose at an annual rate of 4.9 percent. Between 1980 and 1995, coal, electricity and oil consumption for agriculture grew by 1.4 percent, 5.2 percent and 2.4 percent per year, respectively (Table 14.3).

Table 14.3. Agricultural income and energy consumption in agriculture by fuel type in China, 1980-1995 (rates of growth in brackets)[a]

Year	1980	1985	1990	1995
Agricultural income (Billion Yuan; prices 1978)[b]	117.2	131.8 (2.4)	178.1(6.2)	241.6 (6.3)
Total agricultural energy consumption (Mtce)[c]	34.7	40.4 (3.1)	48.5 (3.7)	55.0 (2.6)
Coal (Mtce)[c]	13.0	17.7 (6.4)	17.8 (0.4)	16.0 (-2.1)
Electricity (Mtce)[c]	10.2	12.0 (3.3)	16.2 (6.1)	22.1 (6.4)
Oil (Mtce)[c]	11.4	10.6 (-1.4)	14.4 (6.3)	16.8 (3.1)

[a] Rates of growth in brackets: annual average in the preceding five years (in percentage)
Sources: International Statistical Yearbook, 1996-1998, own calculation
[b] Asian Development Bank, 2000; [c] China Statistical Yearbook, 1996-1998

For the period 1980-1995 the rates of growth of respectively agricultural income, total agricultural energy consumption, coal, electricity and oil are 4.9, 3.1, 1.4, 5.2 and 2.4. For the same period the average income elasticities for respectively total energy, coal, electricity and oil are 0.63, 0.29, 1.1, and 0.49.

The rapid growth of agricultural income and commercial energy consumption in China is expected to go on in the period 2000-2020. If agricultural income grows by about 4.9 percent per year through 2020, it is expected to nearly triple to 726.1 billion Yuan by 2020. The commercial energy used for agriculture is expected to grow by about 3 percent per year through 2020, resulting in total consumption for agriculture of about 136 Mtce. Coal, electricity and oil consumption in agriculture are projected to reach 23.1 Mtce, 82.9 Mtce and 30.6 Mtce, respectively, by 2020 (Table 14.4).

Table 14.4. Energy consumption in agriculture by fuel type trends, 1980-2020 (Mtce)

Year	1980	1985	1990	1995	2000	2005	2010	2015	2020
Coal	13.0	17.7	17.8	16.0	17.1	18.4	19.9	21.4	23.1
Electricity	10.2	12.0	16.2	22.1	28.2	36.9	48.3	63.3	82.9
Oil	11.4	10.6	14.4	16.8	18.7	21.2	24.0	27.1	30.6
Total	34.7	40.4	48.5	55.0	64.1	76.6	92.2	111.9	136.8

Sources: 1980-1995: International Statistical Yearbook, 1996-1998; Asian Development Bank, 2000; China Statistical Yearbook, 1996-1998. Projections for 2000-2020: Based on income elasticities mentioned in the text

The trend of rural population and energy demand per capita is an important factor in rural energy projections. At present the population of rural areas totals 860 million, accounting for 70 percent of the nationwide population and about 30 percent of the world rural population (International Statistical Yearbook 1996-1998; World Energy Council 2000). The population is projected to drop gradually because some of the rural households will migrate to cities, as result of the rapid development of the national economy after 2000. By 2010 and 2020 the population of rural areas is expected to total 770 million and 710 million, respectively, accounting for about 54 percent and 50 percent of nation's total. The gradual decrease of rural population will be helpful to relax the tension between demand and supply of rural commercial energy. Per capita commercial energy consumption for rural households living, however, was only 0.14 tce in 1995. In 1996 over 72 million people in remote rural China were still not connected to the grid (Battelle Memorial Institute 1998).

Both the level and consumption of energy demand are affected by changes in per capita income. In general, the more advanced an economy and the higher personal income, the greater the demand for energy-using

equipment. This means that with the growth of per capita income of rural households, new energy demand, especially the demand for high-quality energy, will increase significantly. Between 1989 and 1995, the real per capita net income of rural households increased from 253 Yuan to 318 Yuan (China Statistical Yearbook 1998; Asian Development Bank 2000), while rural demand for high-quality energy grew rapidly. According to Li and Zhang (1998) total commercial energy consumption for rural household's living is projected to reach 375.9 Mtce by 2020. Coal, electricity and oil consumption for rural household's living is expected to reach respectively 229.1 Mtce, 135.3 Mtce and 11.5 Mtce by the year 2020 (Table 14.5).

Table 14.5. Commercial energy consumption for rural households living by fuel type, 1995-2020 (Mtce)

Year	1995	2000	2005	2010	2015	2020
Coal	87.5	122.3	152.7	190.6	208.9	229.1
Electricity	31.3	55.1	73.8	98.7	115.6	135.3
Oil	2.4	3.9	5.5	7.7	9.4	11.5
Total	121.2	181.5	232.2	297.2	334.3	375.9

Source: Li and Zhang (1998)

Coal, which is available in most areas in rural China at low cost and which provides 59 percent of total commercial energy demand in rural China, is expected to continue to dominate the energy balance in rural China for household's living. This corresponds to an increase in coal consumption in rural China from 87.5 Mtce in 1995 to 229.1 Mtce in 2020, with increasing pressure on the environment. Coal consumption is the main source of local air pollution, acid rain and GHG emissions. Reducing the rural economy's heavy reliance on coal may decrease local environmental damage. Health damages and agriculture losses due to coal-related air pollution in China are currently estimated to be as high as 6 percent of GDP (World Bank 2000).

To lower the proportion of coal use in energy consumption in rural China on a large scale, would involve a wide range of measures, including more energy conservation and adoption of improved coal utilization methods. Substitution of cleaner sources of energy for coal is ultimately required to meet growing energy demands in an environmentally sustainable way and renewable energy could play a role in meeting energy demand in rural China.

Table 14.5 also indicates that rural electricity demand for households is expected to grow faster than the other commercial energy demand in rural areas. Economic development leads to increased reliance

on electricity to meet the base electricity needs for over 72 million people in rural areas still not connected to the grid. Moreover, electricity demand for those people will be satisfied by speeding up the development of rural renewable energy technologies in line with the local conditions because grid expansion is too slow and expensive, especially if only a few households are to be connected. Until more households join the network, the power price in a north-east China village is about US$ 0.6 per kWh, more than 10 times the average price in urban areas (China Government 2000c).

Non-commercial energy obtained from traditional biomass

Most energy from biomass in rural China is used for residential purposes, predominately for cooking. Biomass used for cooking is inefficient compared to fuels such as liquid petroleum gas. A kilogram of wood, for example, generates a mere tenth of the useful heat for cooking delivered by a kilogram of liquid petroleum gas. Biofuels can also cause health damage, because they produce hazardous smoke. Studies of rural areas show that smoke levels inside dwellings often far exceed safe levels recommended by the World Health Organization (Richard 2000). The use of biofuels can also damage the environment, because the search of fuelwood often involves chopping of local trees. Using dung and crop residues as fuel reduces the amount available for use as fertilizer for growing crops. Farmers in some areas in rural China use biofuels in sustainable ways. But in many other areas in rural China the gathering of biofuels are a cause of deforestation, together with logging, and the clearing of land for agriculture. In the northern Chinese county of Kezuo, for example, people have already cut down most of the trees around the farm lands. Poorer households are now turning to even less efficient fuels such as straw and dung (Richard 2000). Hence, reduction in the utilization of traditional biomass with low-efficiency and high-pollution not only requires improvement of rural households' living but also improvement of the efficiency of biomass use and protection of the environment in rural China. In fact energy consumption obtained from traditional biomass was reduced from 267.1 Mtce in 1991 to 202.9 Mtce in 1996, at an annual average decline of 5.3 percent (China Statistical Yearbook 1996-1998).

For a long time, coal, oil and grid-power are regarded as the only modern forms of energy suitable for rural areas in China. However, developing renewable energy technologies, such as solar heating and biomass gasfication systems may contribute to solving energy problems in rural areas.

4. RURAL RENEWABLE ENERGY

Renewable energy projections are important for developing strategies for renewable energy in rural China. Long-term projections of renewable energy in rural China are, however, subject to substantial uncertainties. Sources of uncertainty include not only economic growth and income elasticity of energy demand, but also policies for renewable energy. For our long term projections, we first assume three different cases of income elasticity and combine these with the same average rate of economic growth (4.9%) throughout the projection period (Table 14.6); second, we compare the projected results of the three different cases with that of Li and Zhang (1998), see Table 14.7. We would like to indicate that the projections that we make by means of income elasticities are meant to get an impression of how renewable energy might develop in the future, based on 'what if' questions. We do not pretend that this approach is perfect and we would like to stress that both the assumed rate of growth and the income elasticities may in practice diverge from our assumptions.

Table 14.6. Assumed renewable energy elasticities for the period 1995-2020 for Cases 1-3 and resulting renewable energy growth rate, based on economic growth of 4.9 % per annum throughout the projection period

	Case 1		Case 2		Case 3	
	Income elasticity	Growth rate (%)	Income elasticity	Growth rate (%)	Income elasticity	Growth rate (%)
1989-95	6.3	40	6.3	40	6.3	40
1995-00	6.3	31	3.2	16	6.3	31
2000-05	6.3	31	3.2	16	5	25
2005-10	6.3	31	3.2	16	4.3	21
2010-15	6.3	31	3.2	16	2.8	14
2015-20	6.3	31	3.2	16	1.3	6.4

Table 14.7. Projected rural renewable energy demand for Cases 1-3 and projection of Li and Zhang (1998), 1995-2020 (Mtce)

Year	Case 1	Case 2	Case 3	Li and Zhang
1995	2.6	2.6	2.6	2.6
2000	10	5.4	10	15
2010	148.5	24	79	104
2020	2203	106	207	209

In Case 1, by the year 2020 total renewable energy consumption in rural China is expected to reach 2203 Mtce, which is nearly double to total energy consumption in China in 1995. The projected results of Case 1 are

extremely high and it is likely that the assumed income elasticity of 6.3 cannot be maintained throughout the full period.

In Case 2, where for illustrative purposes the income elasticity is assumed to drop to 3.2 by the year 1995 (equivalent to 50% of the original level), total renewable energy consumption in rural China is expected to reach 106 Mtce in 2020. The results are much lower than those of Li and Zhang (1998). In Case 3 the income elasticity is assumed to gradually decline by 80% from the original level of 6.3 in the period 1989-1995 to 1.3 in the period 2015-2020. Given this rather arbitrary chosen pattern, total renewable energy in rural China is projected to reach 207 Mtce by the year 2020, thus contributing to meeting the needs of the rapidly growing rural economy, improvement of rural households living standard and protection of the environment. These results are comparable to those of Li and Zhang (1998), see Table 14.7. The three cases clearly demonstrate how sensitive the results are for the assumptions on the development of the income elasticity of renewable energy.

5. DISCUSSION AND CONCLUSION

To meet the rapidly growing demand for renewable energy in rural China in the future, it is necessary to accelerate the supply of renewable energy in rural China. Many problems need to be solved in order to enhance the development of rural renewable energy. These problems include shortage of capital, low levels of technology, lack of skilled labor, insufficient commercial experience, lack of information, underdeveloped linkages with the financial community and insufficient access to credit.

How to solve these problems? From a strategy point of view, development should rely on support from both the government and the private sector, including Chinese companies and financing institutions. At the same time it is very important to enhance international cooperation for the supply of renewable energy in rural China.

It is beneficial not only for China, but also for foreign companies and institutions to develop international cooperation for renewable energy in rural China. It will provide foreign companies and institutions with business opportunities. The government of China constantly pays great attention to the development of renewable energy.

There are many favorable ways of international cooperation for the development of renewable energy in rural China. These ways include introducing advanced technology, exchanging information, training labor, and building demonstration projects for the development of renewable

energy. In addition, it is permitted to open joint ventures or establish foreign-owned enterprises in the field of renewable energy.

Our study indicates that there is a huge potential for China to speed up developing rural renewable energy. China's rural areas have abundant potential of renewable energy resources. Nevertheless in 1995 renewable energy consumption in rural China was only about 2.6 Mtce, accounting for about 0.7% of total consumption of rural energy.

In addition, our study shows that with the rapid development of China's rural economy, the scope for renewable energy will increase significantly. In our study renewable energy consumption in rural China is expected to increase from 2.6 Mtce in 1995 to possibly about 200 Mtce in 2020. The projection of renewable energy demand is based on projected growth rate for agricultural income and various projections of the development of the income elasticity over time. It should however be emphasized that both the rate of growth of income and the development of the income elasticities are very uncertain.

We are convinced that it is necessary for China to accelerate the development of renewable energy in rural China in order to meet the rapid growth in the demand for sustainable energy in rural China in the future. Many problems, however, need to be solved in order to enhance the development of rural renewable energy.

NOTES

[1]This study was financed by EU-China Higher Education Cooperation Programme and completed at Wageningen University, The Netherlands, in the period December 1999-May 2000.

[2]Million tonnes of coal equivalent.

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Chapter 15

DETERMINING EFFICIENT BIO-FUEL TAX EXEMPTION POLICY IN FRANCE FOR GREENHOUSE GAS EMISSION ABATEMENT

Stelios Rozakis, Jean-Claude Sourie and Daniel Vanderpooten

1. INTRODUCTION

This chapter presents a micro-economic modeling framework for decision-making on tax exemptions and bio-fuel production levels allocated to the French bio-fuel industry. The agricultural sector is represented by about 700 arable cropping farms upon which energy crops can be cultivated. Processes undertaken where biomass is transformed into bio-fuel include ester and ethanol chains. Agriculture and industry data and technical performance parameters are projected for the year 2002.

The government acts as a leader, since bio-fuel chain viability depends on subsidies. Budgetary, environmental and social concerns will affect policy decisions, whereas farmers and the industry are assumed to act rationally. A multi-criteria optimisation module is used to assist in decision-making when conflicting objectives are involved.

Cost-effective tax credit levels and bio-industry configurations have been determined. Trade-offs are estimated for different targets of public expenditure and CO_{2eq} emission abatement.

The French bio-fuel program was launched in 1993 with the decree of a tax exemption for bio-fuels[1], as a result of fuel supply uncertainty and environmental concerns. Set aside land obligations by the revised Common Agricultural Policy of 1992, that aimed at controlling cereal over-production, created a favourable environment for growing non-food crops[2] and has been the decisive factor that incited farmers to produce energy crops in sufficient quantities to supply bio-fuel industry. As a matter of fact, the part of energy crops cultivated in land set aside increased to reach 30% in 1999 (Figure 15.1).

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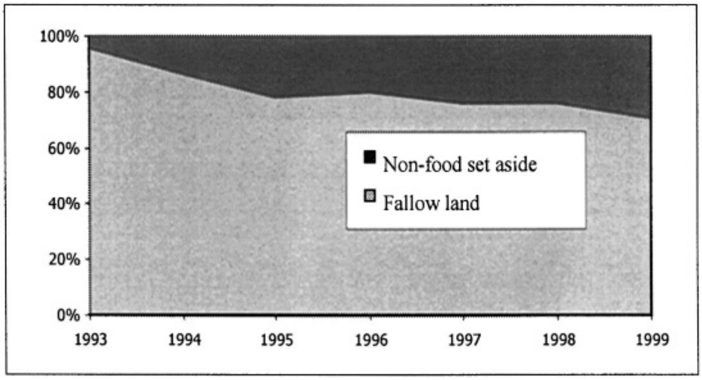

Figure 15.1. Fallow land and obligatory set aside land cultivated by energy crops in France per total set aside surface (%) during the period 1993-1999

Bio-fuels produced in France are rape-seed methyl esters (RME) to be used in diesel engines and ETBE (ethyl tertio-butyl ether) extracted from wheat and sugar-beet for gasoline engines. Total quantity of bio-fuels production reaches currently about 600 thousand tons or 1% of the national liquid fuels consumption. The conversion of biomass to bio-fuels is concentrated at a few plants whereas the agricultural raw material is produced by thousands of farms located in different parts of the country, at various costs. Total production is expected to increase as new agreements will be allocated to the industry by the government and three supplementary conversion units by 2002, so that production of RME and ETBE will reach 387 and 374 thousand tons respectively.

About 7 years after the take-off of the tax exemption program, bio-fuels are still more costly than fossil fuels and the agro-energy industry activity largely depends on government subsidies for its viability. Earmarked funds for financing the tax exemptions have reached 1.4 billion francs in 1999. On the other hand, environmental problems have become more acute and international commitments mean that Greenhouse Gas (GHG) emissions abatement require intensified efforts. Given that biofuel substitution for fossil fuels reduces GHG emissions, could subsidies to bio-fuels be justified on the ground of their contribution to attenuate the greenhouse effect? Even if the recent rise in crude oil prices alleviates the budgetary burden that bio-fuels represent, the question raised by economists concerning the efficient allocation of this amount among bio-fuel chains through tax exemptions to the bio-fuel processors is of primary importance (Sourie and Rozakis 2000)[3].

In order to respond to the above questions, an analysis of bio-fuel production system in France has been done for the period till 2002, when the first period of the C.A.P. reform implementation (known as 'Agenda

2000') will be completed. Production costs are estimated taking into account genetic and agronomic progress regarding all arable crops as well as technology advances resulting in economies of scale at the biomass transformation level. Spatial diversity of arable cropping farms cultivating energy crops is considered.

A systemic analysis has been implemented where all bio-fuel chains compete for the agricultural land in obligatory set aside regime and share the earmarked budget fixed by the government. A bi-level mathematical programming model determines optimal bio-fuel chains' production levels (quantities of energy crops produced, transformation units and bio-fuel quantities). Its results include values of total public expenditure and agents' surpluses as well as GHG emission savings corresponding to any proposed activity level.

French government fixes both unitary tax exemptions and production levels for each bio-fuel chain. For this reason, for any unitary tax exemption set, the model provides the decision-maker (DM) all possible (resulting in benefits greater than zero for both chains) alternative industry activity levels per chain. Considering alternatives for all sets of tax exemptions the DM can select a tax exemption set and a bio-fuel production level scheme that ensures chain viability and respects budgetary constraints while including other aspects such as environmental targets. Thus, a methodology able to propose efficient[4] compromise solutions has to be applied. For this purpose an interactive multi-criteria method based on the reference point approach (Wierzbicki 1982) has been implemented.

The chapter is organised as follows. First the context of the analysis and the case study is presented. A bi-level micro-economic model, that consists of two parts concerning the agricultural sector and bio-fuel industry, is presented in the second section. Next, an appropriate decision support methodology is proposed that integrates multiple criteria, followed by illustrative examples and concluding remarks.

2. THE CASE STUDY

Energy crops are cultivated mainly in two types of arable crop farms: sugar-beet producing exploitations and cereal oriented exploitations producing also rape-seed. Farm Accounting Data Network (FADN) data (orientations OTEX 13 and 14) on number of farms per type, surfaces cultivated, and land set aside concerning the above farm types have been used in this exercise along with detailed data on inputs of arable crops used by each farm (Sourie *et al.* 2000). The year 1996 has been chosen as the basis because the percentage of land set aside then fixed by the C.A.P. at

10% of the surface of cereals and oil and protein seeds, equals the one fixed by the Berlin agreement for the period 2000-2002. The horizon 2002 is taken as reference for the reason that CAP reform of 1999, will then be totally applied, after two years of transition 2000-2001. Arable farms that cultivate energy crops include a sample of 216 farms located in the cereal production oriented region of the North-East Ile-de-France) and 465 farms in Northern France where sugar-beet is allowed to the arable crop mix. Profiles of the two groups are shown in Table 15.2. These farms represent adequately the diversity of arable cropping farms in France. Weights applied to the sample of farms available have permitted to represent the universe of these farm types according to FADN (‘weight1’, Table 15.1). Extrapolation procedures permit to approximate magnitudes of energy crops cultivated in land set-aside at the national level (‘weight2’ column, Table 15.1).

Table 15.1. Number of farms and land set aside in the year 1999

	Number of farms			Set aside land (ha)		
	population A	sample B	weight1 A/B	population C	sample D	weight2 C/D
Cereal farms	48236	216	223.3	537773	3852	139.6
Sugar-beet farms	32765	465	70.5	232000	3978	58.3

Agricultural production model takes into account agronomic constraints applied to all individual farms. First, some crops are not allowed to be cultivated in more than a certain percentage of the arable surface of the farm (for instance, rape-seed, food and non-food included, is limited to 30%). On the other hand, rotation with sugar-beet, peas, and rape-seed limits cereal mono-culture. As a result of the above constraints, energy crop introduction to set-aside land will make decrease surface covered by related food crops. For instance, regional statistics confirm that when rape for energy is cultivated in land set aside, food rape-seed cultivated surface is going to decrease.

In Table 15.2, the original crop mix (output of the agricultural sector model when energy crop prices are set at zero) is shown for cereal and sugar-beet specialising regions. In the last two columns, changes in surfaces allocated appear as a result of the creation of a market for rape-seed for energy (price equal to 100 FF q^{-1}). One can observe that energy rape-seed is cultivated entirely on land set-aside whereas food crops are re-allocated due to agronomic constraints. Food rape-seed is decreased especially in the cereal region because of its important acreage. Wheat mono-culture is slightly increased because a decrease of surfaces cultivated by preceding crops.

Technical coefficients of conversion of biomass-to-energy as well as costs of state-of-the-art plants of rather big size taking into account economies of scale effects are used in the model so that bio-fuel chains performance approximate medium term conditions (year 2002). Parameter values used in the industry model appear in the Tables 15.3-15.5.

Table 15.2. Crop mix with and without energy crop (results agricultural sector model)

	Scenario 'no energy crops'				100FF/q for ester rape-seed	
in ha	cereal farm region		sugar-beet producing region		cereals	sugar-beet
	hectareage	profile	hectareage	profile	Changes in hectareage	
Arable land	7816744	%	4038709	%	0	0
Wheat	906415	0.12	935061	0.23	-34560	-4537
Wheat mono-culture	3282808	0.42	1267354	0.31	60150	3954
Wheat preceded peas	-	-	257653	0.06	0	2425
Wheat in set-aside	-	-	0	-	0	0
Barley	545804	0.07	115591	0.03	0	0
Winter barley	2071253	0.26	220237	0.05	8970	1011
Corn	288961	0.04	0	-	1772	0
Fresh peas	-	-	43103	0.01	0	0
Rape-seed	447984	0.06	69433	0.02	-37586	-6538
Sunflower	4121	0.00	0	-	0	0
Peas	-	-	258318	0.06	0	2425
Potatoes	-	-	155458	0.04	0	0
Sugar-beet	-	-	587226	0.15	0	0
Beans	-	-	13257	0.00	0	0
Sugar-beet ethanol	-	-	0	-	0	0
Wheat ethanol	-	-	0	-	0	0
R.M.E.	-	-	0	-	193235	61931
Set aside land	269398	0.03	116018	0.03	-191982	-60671

Table 15.3. Cost structure of bio-fuel industry

Chain	RME	ethanolBig	ethanolSmall	
Capacity	1.4	0.99	0.2	M hl
Variable costs	48	111.46	146.24	FF hl^{-1}
Fixed costs	144.72	94.86	24	10^6 FF (annual amortisation)

Table 15.4. Indicative market prices of products and by-products of bio-fuel chains

	ester	cakes	glycerine	ethanol	DDGS[a]
Market price	0.9 FF l^{-1}	650 FF t^{-1}	3000 FF t^{-1}	0.6 FF l^{-1}	700 FF t^{-1}

[a] DDGS: Distilled dried grain solubles.

Table 15.5. Technical coefficients of biofuel production activity

Production phases	category	element	units	ETBE	ETBE	Ester
				sugarbeet	wheat	rapeseed
Stage 1 :	resource	agricultural land	ha	0.07	0.19	0.64
agricultural production	input	agric. biomasse	t	5.9	1.7	2.50
Stage 2 :	output-input	ethanol	l	587.85	587.85	
1st transformation phase	output	draff	t		0.70	
	output-input	rape-seed oil	t			1
	output	cakes	t			1.40
Stage 3 :	input	methanol	t			0.1
2nd transformation phase	input	iso-butane	t	0.58	0.58	
	output	biofuel weight	t	1	1	1
	output	biofuel volume	l	1333.3	1333.3	1136.0
	output	glycerine	t			0.10

NOTE: t= metric ton, hl: hectoliter equal to 100 liters.

3. MODELLING THE BIO-FUEL PRODUCTION SYSTEM

The micro-economic model represents the agro-energy chain mechanics and cost structure by simulating the farmers and industry behaviour to assist the government in evaluating support policies. Taking into account tax exemptions and activity levels exogenously fixed along with industry cost structure, and material input cost (based energy crop supply curves) agents' surpluses can be estimated as shown graphically in Fig. 15.2.

The integrated model that simultaneously optimises economic surplus in the two-chain bio-fuel system is a MILP bi-level model based on mathematical programming principles. It can minimise the social cost (budget cost – agents' surpluses) of environmental policy to mitigate global warming by determining tax exemption values per unit of biofuel volume and activities for both chains given a fixed amount of government expenditure.

The bio-fuel industry is vertically optimised with the use of two-level programming that combines agricultural and industrial activities. Bard *et al.* (1998) formulated bi-level programming methods to solve this problem and have proposed a non-linear program (NLP), where the model determines simultaneously tax exemptions and energy crop prices. For

problems of big size they used though a grid search algorithm to overcome the limits of the NLP by searching over all possible unitary tax exemptions for the two bio-fuels concerned. Prices at the plant gate have been determined by solving the farm linear programming (LP) model.

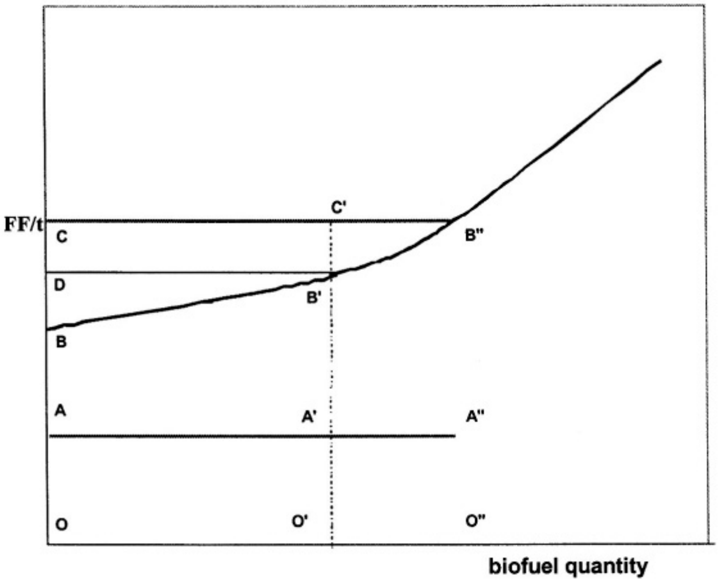

Figure 15.2. Economic surpluses generated by the bio-fuel production and tax exemption process

Tax exemption to biofuels (no budgetary constraints)

BB'B": biofuel marginal cost=biomasse opportunity cost+conversion cost-coproduct value
OA: biofuel market price (perfectly elastic demand curve)
OC: biofuel value=biofuel market price + tax exemption (AC)
OO´´: quantity produced at the equilibrium level (biofuel value equal to its marginal cost)
CBB´´: producer (agricultural sector) surplus
CB´´A´´A: total cost to the government of the biofuel support program
ABB´´A´´ = CB´´A´´A - CBB´´: deadweight loss

Tax exemption of biofuels under budgetary constraint

CC´A´A: total budget earmarked to biofuel
OO´: biofuel quantity produced (agreements approved by the government that depend on earmarked budget)
CA: tax exemption to biofuel (depends on budget)
DBB´: producer (agricultural sector) surplus
DCC´B´: industry surplus
ABB´A´ = CC´A´A - DBB´ - DCC´B´´: deadweight loss

In this chapter we generalise this approach by searching successively over the grid of unitary tax exemptions and the grid of prices of energy crops. Furthermore, capacities and industrial processes have been included as variables in the industry model in order to have a more realistic representation of possible bio-energy carriers configurations of the French bio-fuel industry, illustrated for the wheat-to-ethanol and rape-seed-to-ester processors[5].

The model operates on two levels. First, the agricultural sector regional problem is solved. A model determines the amount of crops offered to the market for different sets of crop prices. Among these crops, *m* energy crops are processed by *n* bio-fuel systems. Then, the industry model considers supply provided by the agricultural sector, and, given unitary tax exemptions, proposes activity levels resulting in positive profits for bio-fuel industry.

3.1 The agricultural sector model

A large number of sub-models each corresponding to a particular farm are articulated in a staircase form to modelise the agricultural sector. The agricultural sector model belongs to the MAORIE family of models (Carles *et al.* 1997) and its specification is shown in Box 1. Farmers maximise their gross margin subject to resource (arable land availability), institutional (set aside obligation, sugar-beet quota) and agronomic (crop rotation) constraints.

Box 1. Agricultural sector model specification

Indices

$c \in C$	index for food crops, ($c = 1$ for sugar beets)
$d \in D$	index for energy crops ($D =$ {wheat, rape-seed}), ($\lvert D \rvert = m$)
$f \in F$	index for farms
$b \in B$	index for bio-fuels ($B =$ {ethanol, ester}), ($\lvert B \rvert = n$)
$k \in K$	index for agronomic constraints
$j \in J$	index for *m*-tuples of prices (for each energy crop)

Parameters

$g_{c,f}$	gross margin for food crop *c* grown on farm *f* (FF/ha)
$y_{d,f}$	yield of energy crop *d* grown on farm *f* (tons/ha)
s_d	subsidy paid to farmers for energy crop *d* (FF/ha)
$c_{d,f}$	production cost for energy crop *d* on farm *f* (FF/ha)
γ	subsidy to land set aside (FF/ha)
w_f	multiplier used to scale up arable land of farm *f* to the national level
σ_f	total arable land available on farm *f* (ha)

$\sigma_{1,f}$ land available on farm f for sugar-beet for sugar production (ha)
θ fraction of arable land that must be set aside (for 1998: 10 % of total cultivated land for cereal, oil and protein seeds)
π_k maximum fraction of land permitted for crops included in agronomic constraint k
i_{ck}, i_{dk} binary coefficients of agronomic constraints ($i_{ck}=1$ if food crop c is concerned by agronomic constraint k, 0 otherwise; $i_{dk}=1$ if energy crop d is concerned by agronomic constraint k, 0 otherwise)

Decision Variables

p^j_d (parametrically treated) price at farm gate for energy crop d for j^{th} set of prices (FF/t)
$xf^j_{c,f}$ area allocated to food crop c on farm f (ha) for j^{th} set of prices (ha)
$xe^j_{d,f}$ area allocated to energy crop d on farm f (ha) for j^{th} set of prices (ha)
xs^j_f area set aside on farm f (ha) for j^{th} set of prices (ha)

For each m-tuple of prices $j \in J$ consider the following model

$$max \sum_{f\in F}\sum_{c\in C} g_{c,f}\, xf^j_{c,f} + \sum_{f\in F}\sum_{d\in D}\left(p^j_d y^j_{d,f} + s_d - c_{d,f}\right) xe^j_{d,f} + \gamma \sum_{f\in F} xs^j_f \qquad (1)$$

subject to:

Land resource constraints

$$\sum_{c\in C} xf^j_{c,f} + \sum_{d\in D} xe^j_{d,f} + xs^j_f \le w_f \sigma_f \qquad \forall f \in F \qquad (2)$$

Set aside constraints

$$\sum_{d\in D} xe^j_{d,f} + xs^j_f = \theta w_f \sigma_f \qquad \forall f \in F \qquad (3)$$

Quota on sugar beets

$$x^j_{1,f} \le w_f \sigma_{1,f} \qquad \forall f \in F \qquad (4)$$

Rotation constraints

$$\sum_{c\in C} i_{c,k} xf^j_{c,f} + \sum_{d\in D} i_{d,k} xe^j_{d,f} \le \pi_k w_f \sigma_f \qquad \forall f \in F, k \in K \qquad (5)$$

Non-negativity constraints:

$$xf^j_{c,f}, xe^j_{d,f}, xs^j_f \ge 0 \qquad \forall c \in C, d \in D, f \in F \qquad (6)$$

Quantities of energy crops for each combination j

$$q^j_d = \sum_{f\in F} y_{d,f} xe^j_{d,f} \qquad (7)$$

The outputs of the agricultural model are quantities of crops provided by the agricultural sector. These depend on food crop prices and energy crop prices offered by the bio-fuel industry. More precisely, for each m-tuple of prices, $j \in J$, and for each energy crop $d \in D$, the agricultural model provides the quantities q^j_d proposed by the farmers. Note that these quantities are not determined independently; they take into account cross-price effects between energy crops, as shown in Figures 15.3 and 15.4. In this case, two energy crops, namely wheat-to-ethanol and rape-seed for RME, are used as representative energy crops.

A grid of all possible prices at which energy crops can be sold at the farm gate is constructed (which defines the set J). Prices that fall outside this grid are either too low resulting in zero quantities being produced, or too high without any additional quantity produced. Then, we perform successive solver iterations using all possible pairs of prices ($p_{wheat} = \{27, ..., 65\}$ and $p_{rape\text{-}seed} = \{40, ...,135\}$ in FF q^{-1}, where q is the quintal each of which equals 100kg) in order to obtain, for each pair, optimal quantities produced as well as all relevant magnitudes (*e.g.* land cultivated for energy crops, set aside land, agricultural sector surplus). The agricultural surplus is the producer surplus that corresponds to the difference between the values of the agricultural sector model objective function with and without energy crops.

3.2 Industry sector model: specification and parametric solution process

This model takes as inputs crop quantities q^j_d determined by the agricultural model (see equation 7, in Box 1). Each bio-fuel chain $b \in B$ can make use of these available quantities so as to produce bio-fuels considering technical and economic conditions of production (including crop prices, transformation costs, market prices and tax credits granted by government); capacity rigidities are taken into account and technological advances have been considered. Under these conditions each chain aims at maximising its own profit.

One or more energy crops can be processed by one or more bio-fuel chains. A binary relation $R \subset DxB$ indicates which combinations between energy crops and bio-fuel chains are considered.

The industrial model includes conditions for the production of these bio-fuels based on current conversion technical coefficients (Table 15.5), based on a single size of transformation capacity for ester and two sizes for ethanol production units.

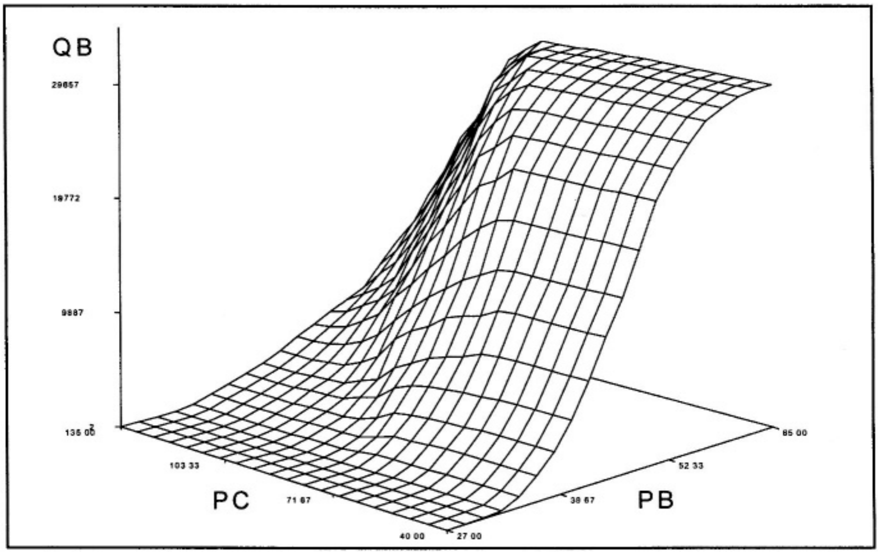

Figure 15.3. Quantity of wheat (QB) result of parametric solution (prices of rape-seed PC and wheat-to-ethanol PB in the horizontal axes) of the agricultural model (in kt, prices in FF q^{-1})

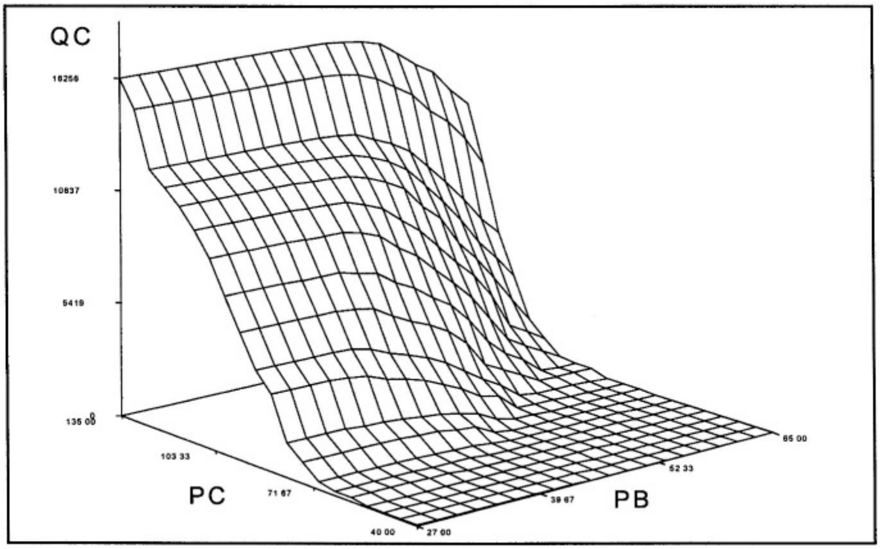

Figure 15.4. Quantity of rape-seed (QC) result of parametric solution (prices of rape-seed PC and wheat-to-ethanol PB in the horizontal axes) of the agricultural model (in kt, prices in FF q^{-1})

The grid, derived from the agricultural sector model, provides the industry model with a number of scenarios corresponding to the elements

of set *J*. Each scenario, or each line in the grid, includes energy crop quantities produced, or surfaces cultivated (variables in the agricultural sector model). Prices of energy crops at the plant gate represent costs of raw material inputs for industry. Then capacities of transformation units required to process these quantities, bio-fuel quantities produced, industry surpluses, and finally total government spending, can be determined using parameters related to the bio-fuel chains examined (Box 2, industry model).

Box 2. Bio-fuel industry model specification

Indices (additional to the agricultural sector model, see Box 1)

$bp \in Bp$ index for bio-fuel by-products (*Bp* = {DDGS, rape-seed cakes, glycerine}), $(\mid Bp \mid = o)$

$j \in J$ index for *m*-tuples of prices (for each energy crop)

$r \in R$ index for couples of 'energy crop converted to bio-fuel'

$R \subset DxB$ binary relation that indicates all combinations between energy crops and bio-fuel chains

$s \in S$ index for couples of 'by-product related to bio-fuel'

$S \subset BpxB$ binary relation that indicates all combinations between energy crops and bio-fuel chains

$k \in K$ index for binary variables of conversion units (for each bio-fuel), *k={1,2,3,4}*

$l \in L$ index for *n*-tuples of unitary tax credits (in case of parameterisation)

Parameters (additional to the agricultural sector model, see Box 1)

P_r bio-fuel *b* market price (FF/hl)

P_s by-product *bp* market price (FF/hl)

CV_r variable conversion cost of energy crop *d* to bio-fuel *b* (FF/hl)

FC_r fixed cost of crop *d* processed to produce biofuel *b* (FF)

A_r technical coefficient of conversion of crop *d* to bio-fuel *b* (hl/t)

A_s technical coefficient of conversion of crop *d* to bio-fuel *bp* by-product (t by-product/t biofuel)

G maximum total public expenditure allowed for bio-fuels (FF)

GH_r coefficient of GHG saved per ton of bio-fuel produced (t CO_{2eq}/t biofuel)

CP_r capacity of transformation unit (h1/year)

CF_r coefficient of transformation of volume to mass (h1/t)

Decision variables

DF^l_r (parametrically treated) tax credit to industry for bio-fuel *b* (FF/hl)

$$\delta^j = \begin{cases} 1, if_the_j^{th}_set_of_prices_is_selected \\ 0, otherwise \end{cases}$$

i_r number of conversion units for processing bio-fuel *b*

$bi_{r,k}$ transform number of conversion units for processing bio-fuel *b* in discrete variables

q^j_r quantity of energy crop *d* processed by conversion unit of bio-fuel *b* (t)

q_r quantity of bio-fuel produced by chain r (t)

For each n-tuple of unitary tax credits $l \in L$, consider the following model:

Greenhouse gas emissions abatement

$$z_{env} = \sum_{r \in R} GH_r^j \delta^j q_r^l \tag{8}$$

where individual bio-fuel chain profits are:

$$z_r = \left(DF_r^l + P_r\right) q_r - CV_r q_r^l + \sum_{s \in S} P_s q_s - \sum_{j \in J} P_d^j Q_d^j \delta^j - FC_r i_r \quad \forall r \in R \tag{9}$$

subject to:

$$z_r \geq 0 \quad \forall r \in R \tag{10}$$

Budgetary constraint

$$\sum_{r \in R} DF_b^l q_r \leq G \tag{11}$$

Capacity constraints

$$i_r \geq \frac{CF_r q_r}{CP_r} \quad \forall r \in R \tag{12}$$

Conversion units transformation to discrete variables

$$i_r = \sum_{k=1}^{4} 2^{k-1} bi_{r,k} \quad \forall r \in R \tag{13}$$

Biomass conversion to biofuel balances

$$\sum_{r \in R} A_r q_r^l = q_r \quad \forall r \in R \tag{14}$$

Biomass conversion to biofuel by-product balances

$$\sum_{s \in S} A_s q_r^l = q_s \quad \forall s \in S \tag{15}$$

Raw material availability constraint

$$q_r^l \leq \sum_{j \in J} Q_d^j \delta^j \quad \forall r \in R \tag{16}$$

Selection of a unique m-tuple of prices

$$\sum_{j \in J} \delta^j = 1 \tag{17}$$

Non-negativity and integrity constraints

$$q_r^l \geq 0, i_r \in \text{int}, bi_{r,k} \in \{0,1\}, \delta^j \in \{0,1\} \tag{18}$$

At this point, the government must select among these scenarios one that is satisfying for both chains (in terms of profits) so that it will make sure that they will be willing to produce. Industry is not considered as single neutral agent aiming at break even point, but as distinct and competing agents aiming at maximising their own profits. Each *n*-tuple of unitary tax credits $(l \in L)$ gives rise to different solutions. In order to generate the efficient frontiers for each *n*-tuple, a modified version of the so-called ε-constrained approach is implemented (Steuer 1986). In this case, it consists in maximising the first objective subject to varying lower bounds on the other objectives. As indicated below, the industry model is solved parametrically for different values of ε_k.

$$max\, z_1\left(q_{d,b}^l, i_b\right) + \rho \sum_{k=2}^{n} z_k\left(q_{d,b}^l, i_b\right) \tag{19}$$

subject to

$$z_k\left(q_{d,b}^l\right) \geq \varepsilon_k \qquad (\text{k} = 2,\ldots,\text{n}) \tag{20}$$

and constraints (8) to (18), where ρ is a small positive value (0.01) and ε_k (in MFF) vary parametrically from the lowest to the highest possible profits for chains *k (k*=2,...,*n).* Note: the objective function has been slightly modified in order to discard weakly efficient solutions.

Consequently, during this second stage of the bi-level model, each pair of tax credits provides a fair number of economically rational solutions from the point of view of agricultural and industry sectors. We keep all these solutions in order to provide the multi-criteria analysis module with a final set of alternatives reflected in the decision space as discrete choices.

4. MULTIPLE CRITERIA ANALYSIS

Government opts for other priorities beside budgetary concerns such as supporting farmers' income, diversifying energy production sources and reducing oil imports and, last but not least, reducing greenhouse gas emissions (GHG). Bio-fuel use can reduce fossil fuel consumption and increase carbon storage in plants. When bio-fuels are burned, the CO_2 absorbed by the growing plant during photosynthesis is re-emitted. Therefore, on a global basis, no net CO_2 emissions would occur, if biomass

production was maintained to replace material that is burned and no fossil fuels were used in the production and conversion processes. In practice though, fossil fuels are used in the bio-fuel production process (fertiliser manufacturing, farm machinery operation, energy during conversion of crops to bio-fuels). The overall effect on net CO_2 emissions then depends on the balance between this fossil fuel use and the fossil fuels displaced by the bio-fuels. Studies attempting to estimate environmental externalities from bio-fuel production in France have been based on Life Cycle Analysis (LCA)-estimates by OECD/IEA (Vollebergh 1997). *CO_{2eq} savings* are reported in Table 15.6:

Table 15.6. Effects on greenhouse gases emissions

	t CO_{2eq} saved /t of biofuel	t CO_{2eq} saved / ha
RME vs. diesel	2.2	2.78
Ethanol vs. gasoline	1.4	2.75

Source: Reinhardt (1998) and Scharmer-Gosse (1996)

According to the Kyoto Summit of December 1997, E.U. countries should reduce their global emissions by 8% (1990 basis) by the commitment period 2008-2012; obligations for France amount to stabilising of GHG emissions at 1990 levels, which implies the need for prompt additional efforts, as GHG emissions have been increased by 5.9% in the period 1990-1998 (CITEPA 2000).

Regarding the contribution of the bio-fuel system activity to the GHG emission abatement, it would be interesting to measure the ratio of economic welfare (net economic effect of the activity calculated as the difference between gains -industry and agricultural surplus- and budget losses per ton of CO_{2eq} saved. This 'cost-effectiveness' factor indicates how much society has to sacrifice to abate GHG emissions by one ton when switching from fossil fuel to bio-fuels. However, this indicator proves to be insufficient for decision making. As we can observe in Figure 15.5 different configurations corresponding to various activity levels, result in close 'cost-effectiveness factor' values.

In Table 15.7, two groups of solutions are presented, namely A, B, and C that require minimal budget expenses whereas the second group (represented by D and E) tends to exhaust available funding allocated to the activity taking into consideration other factors such as engagements for GHG emission reduction, and farmer organisations pressures. Alternatives C and E that represent very different activity levels result in quasi-equal cost-effectiveness factor values. Additional elements (criteria) are needed to assist in decision-making. C is preferable in terms of budget expenditure but it is dominated by E in terms of farmers' income and in GHG emission

abatement which results in much higher activity levels especially concerning RME production.

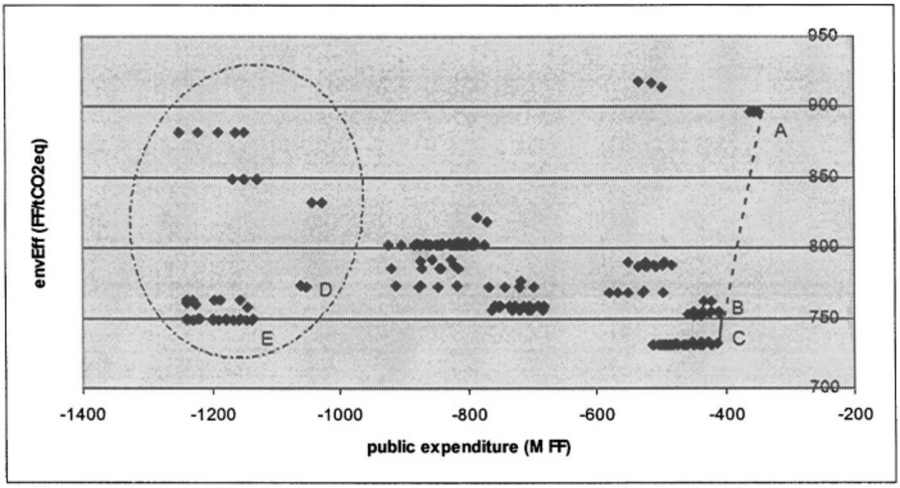

Figure 15.5. Alternative bio-fuel industry configurations in the decision space shaped by the 'public expenditure' and the 'cost-effectiveness factor' measures of performance

Table 15.7. Cost-effectiveness factor and other criteria values of selected alternatives

	Public expenses MFF	Ceff[a] FF/CO_{2eq}	Q_{ester} 10^3t (#plants)	$Q_{ethanol}$ 10^3t (#plants)	tax exemption Ester FF hl^{-1}	tax exemption Ethanol FF hl^{-1}	fs[a] MFF	GHG savings 10^3t CO_{2eq}
A	348	897	52 (1)	152 (1)	210	250	31	33
B	409	754	113 (1)	139 (1)	160	250	40	44
C	413	732	113 (1)	141 (1)	160	250	40	45
D	1052	773	331 (3)	141 (1)	220	270	165	93
E	1147	749	369 (3)	166 (1)	210	270	220	105

[a]*Ceff* and *fs* stand for 'cost effectiveness factor' and 'farmers surplus' respectively.

This implies that, in reality, multiple policy objectives exist behind the pursuit of a single objective, such as budgetary discipline. Therefore, components of the cost-effectiveness factor (chain surpluses, agricultural surplus, public expenditure and the environmental effect) have to be taken explicitly into account since each of them involves different stakeholders such as the farmers, the industry, environmentalists and the government. Thus, a multi-objective programming (MOP) approach would be appropriate (*e.g.* Vanderpooten 1990). As it is extremely difficult and arbitrary to give a relative importance (weight) to each criterion, an interactive approach, which allows an exploration of the efficient solutions and possible trade-offs[6] among criteria, seems more appropriate than any

method aggregating a priori the criteria. For this purpose, the reference point approach (Wierzbicki 1982) has been selected. Aspiration levels, set by the DM, expressed on the criteria onto the efficient frontier resulting in a solution corresponding to a specific tax exemption scheme. The efficient frontier includes all non-dominated alternative choices. The exploration is supported through an interactive adjustment of the aspiration levels on the basis of solutions generated at previous iterations. This approach has been used in various contexts, in particular in contexts involving environmental aspects (Stam *et al.* 1992). The following criteria are proposed in our case: agricultural surplus, industry surpluses, public expenditure, GHG savings (in t CO_{2eq}) respectively estimated by relationships (1), (9), LHS of (11) and (8) in Boxes 1 and 2.

Projection of aspiration levels expressed by the DM is performed by optimising a scalarising function(s) that aims at satisfying the following requirements: (a) *s* must generate efficient solutions only, and (b) all efficient solutions may be generated by *s*.

The first requirement is easily met since we work on the subset of efficient solutions (190 out of 1980 in this case study). In order to satisfy the second requirement, we selected the following scalarising function derived from the weighted Tchebychev norm:

$$s\left(z,\bar{z}\right)=\max_{h=1\ldots p}\left\{\lambda_h\left(\bar{z}_h-z_h\right)\right\} \qquad \text{with } \lambda_h=\frac{1}{\left(z_h^{*}-n_h\right)} \tag{21}$$

and $\bar{z}$ reference point representing aspiration levels
p number of criteria (objectives)
z_h^{*} maximum value on criterion *h* (ideal point[7])
n_h minimum value on criterion *h,* over the efficient set of solutions (nadir point)

Optimising separately for each criterion results in quite different strategies. The pay-off matrix illustrates conflicts among strategies as well as possible trade-offs and provides useful information in a synthetic way. In this case, very similar solutions optimise criteria agricultural surplus and CO_2 savings (one of the solutions optimising agricultural surplus is actually the same as the one optimising CO_2 savings), in other words, interests of farmers and environmentalists coincide. This can be explained as higher production levels and surpluses for farmers correspond to higher GHG reductions.

The decision-making process can be reserved to public policy makers or, alternatively, include stakeholders. During the interactive

process, decision-makers specify aspiration levels to be achieved. Also, worst levels acceptable (reservation levels) may be set for one or more criteria restricting the set of alternatives included in the decision space. Aspiration and reservation levels should be set within efficient ranges of variation. After some iterations, possibilities of compromise and corresponding trade-offs can be explored. In order to initiate the exploratory process, one can start by projecting the ideal point onto the efficient frontier. Discussion is facilitated by different types of dialogues that enhance interaction between DM(s) and the model. Besides focusing search on 'desirable values', the DM can specify minimal requirements on criterion values (reservation levels)[8].

In case of aiming at the ideal point (second column in Table 15.8), the alternative of 1 ester and 2 ethanol transformation units, is selected, corresponding to the unitary tax exemption vector for ethanol and bio-diesel 300 FF hl^{-1} and 220 FF hl^{-1} respectively. This solution seems interesting but it could be improved especially regarding public spending. So, aspiration levels are set at this solution point except for public spending which is attempted to reach its optimum (column 2 in Table 15.8). Projection results in lower expenditures (unitary tax exemptions for ethanol and bio-diesel 300 FF hl^{-1} and 200 FF hl^{-1} respectively), reducing considerably industry profits.

Table 15.8. Pivoting on public expenditures vs. GHG emission reduction

	aspiration levels	Projection	target: budget economies	Proj.	Proj.*	target: exhaust budget	Projection
Tax exempt. RME		220		190	180		220
Tax exempt. ethanol		300		300	280		320
Units RME		1		1	1		2
Units ethanol		2		1	2		2
surplus agr	219	101	101	39.5	101	101	165
surplus ester	212	94	94	76.4	44	94	116
surplus eth	159	99	99	49	60	99	107
budget (min)	348	863	348	494	775	1200	1168
CO_{2eq} savings	1.05	0.71	0.71	0.45	0.71	0.71	0.92

**when reservation level activated for GHG emission abatement level at 0.71 $MtCO_{2eq}$.*

In terms of trade-off between public expenditure and GHG savings, this efficient solution suggests to the DM a solution that decreases the level of CO_{2eq} savings by 26 thousand tons for a budgetary gain of 369 million FF.

When environmental concerns impose minimum performance regarding GHG, a reservation level can be set on criterion 'CO_2 savings'.

In this case, the set of alternatives decreases to 98 candidate solutions and the compromise solution corresponds to increased activity levels (see column ‘projection*’ in Table 15.8). Aspiration and reservation values as well as the compromise solution found by the reference point procedure for this last scenario are illustrated in a five-dimension radar graph (Figure 15.6).

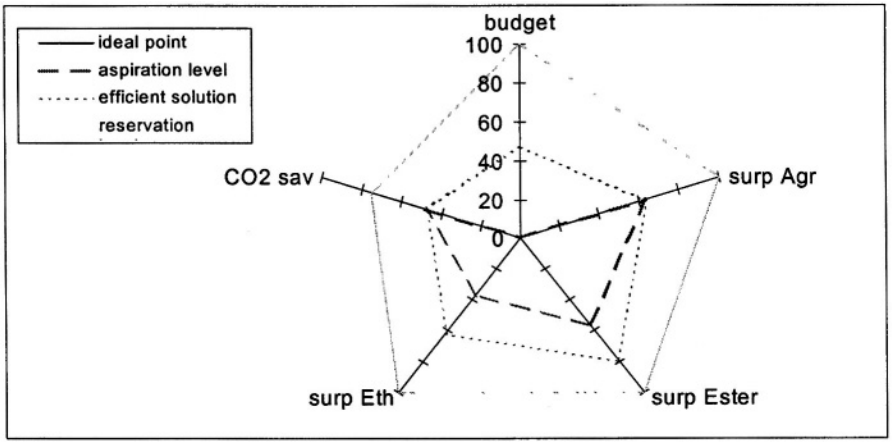

Figure 15.6. Results of the interactive multi-criteria analysis algorithm. Ideal point is the centre of the radar graph

All magnitudes appear in terms of distances from the ideal point (%). By revising aspiration and reservation levels in successive rounds the DM can thus freely but systematically explore the set of efficient solutions.

5. CONCLUSIONS

Modelling agro-energy chains has been attempted through *ad hoc* bi-level mixed integer linear programming. The fact that prices are not computed but introduced parametrically (*ad hoc* formulation) allows us to solve real size problems. The output of this bi-level model is a series of candidate solutions. Generating these solutions requires computation effort that may take several hours. This is acceptable, since it concerns a preliminary stage of analysis where decision makers are not involved. In the decision-making stage, where a specific tax exemption scheme is to be selected among these solutions, we propose an interactive decision support process with immediate response times is implemented. An interactive multi-criteria optimisation module supported the exploration of feasible alternative configurations, on the basis of economic, social and environmental criteria, in an iterative way.

Cost effective tax credits have been determined varying around 220 FF hl^{-1} for ester and 300 FF hl^{-1} for ethanol when trying to find simultaneously a compromise among all objectives. When public expenditure is the first priority, tax credits vary around 180-190 FF hl^{-1} for ester and 280-300 FF hl^{-1} for ethanol. When GHG minimal levels are imposed whereas the earmarked budget is spend entirely, efficient configurations propose higher levels of activity for the RME chain as its performance is better in terms of GHG emission abatement but also of surplus generated for the agricultural sector. All the above values prove to be consistently lower that those currently granted by the government (tax exemptions actually amount at 230 FF hl^{-1} for ester and 330 FF hl^{-1} for ethanol), especially regarding the ethanol chain. Thus, economic analysis of the bio-fuel sector (simulating conditions in the year 2002) suggests that there is margin for efficient policies that could be the result of a consensual interactive process.

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NOTES

[1] Art. 92, Finance law voted by the French parliament in 1992, has established tax exemptions from the I.T.P.P. (Interior Tax to Petroleum Products) for bio-fuels set at 230 FF hl^{-1} for methyl esters and 329.5 FF hl^{-1} for ethanol used in ETBE providing for production agreements of 3 or 9 years for fixed quantities of bio-fuels.

[2] Art. 32, Finance law has rectified, in 1997, the law of 1992 suppressing the obligation of the bio-fuel industry to use energy crops cultivated in land set-aside. However, in practice the supply of energy crops is related to the percentage of arable land to obligatory set-aside.

[3] Tax exemption levels are currently under revision by an expert commission (Levy-Couveinhes) upon request of the French government.

[4] *efficient or non-dominated solutions :* feasible solutions such that no other feasible solution can achieve the same or better preformance for all the criteria under consideration and strictly better for at least one criterion.

[5] Models are written in GAMS code use BDMLP and OSL2 (MILP) solvers (Brooke *et al.* 1998).

[6] *trade-off:* the trade-off between two criteria means the amount of achievement of one criterion that must be sacrificed to gain a unitary increase in the other one.

[7] *idealpoint:* the solution where all the objectives achieve their optimum value

[8] The user can use an interface built in Excel spreadsheet calling Visual Basic procedures to select an aspiration point then project it onto the efficient frontier and eventually visualize the solution in horizontal scroll bars in a dialog box (interface description in Rozakis *et al.* 2001).

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Index

A

accuracy, 53
acid, 210
acidification, 111, 192
ad valorem tax, 52
adoption, 53
afforestation, 135, 137, 139, 140
agricultural income, 209
Agricultural Policy, 217
agricultural reference system, 105
agricultural sector model, 224
agri-environmental policy, 5, 23
agro-energy, 218
Agro-forestry systems, 4
agronomic factors, 121
agronomic model, 192
agronomic, 121, 122, 124
albedo, 143
anaerobic digestion, 183
anthopogenic, 192
artificial nitrogen, 80
artificial regeneration, 141
atmospheric, 92

B

bi-level model, 222
biodiesel, 6, 107
biodiversity, 112, 148
bioenergy, 6, 105, 109, 201
bio-fuel industry, 217
biofuel, 4 211
biogas plant, 177, 185
biogas, , 6 177, 178, 182
biological, 64
biomass fuel, 143
biomass power, 145
biomass systems, 7
biomass, 3, 77, 87, 9, 1052, 135, 138, 151, 179, 211
boreal forest, 141
boundary, 114
budget cost, 222
budgetary constraint, 223

C

canopy, 90
CaO, 28
carbon dioxide, 191
carbon sequestration, 7
carbon, 140
cattle, 186
CH_4-emissions, 195
chemical nitrogen, 18
chicken, 93
climate change, 7, 139, 143
climatic, 122
clover, 194
CO_2 emissions, 41, 137, 143, 146,148, 135, 192, 195, 230
CO_2 emitters, 4, 149, 150
CO_2 mitigation, 4
CO_2, 92, 141
coal, 145
commercial, 135, 208
communication, 23
community, 213
competitiveness, 121, 126
complementarity, 74
conjunction, 126
conservation, 210
consumption, 210
correlation, 22
cost effective tax, 217, 236
cost function, 60
cost minimisation, 63
cost, 90
cost-effectiveness factor, 232
cost-effectiveness, 84

crop protection, 80
crop, 95, 219
cultivation area, 131
cultivation, 37, 78, 115, 127
currency, 64

D

dairy, 93
Data Envelopment Analysis, 11, 14
DEA analysis, 16
decomposition, 57
deforestation, 3,135, 139, 211
degradation, 139
demand analysis, 57
diesel, 107
direct energy, 80
disease, 94, 149
dis-investment, 123
dry matter, 89
Dutch Farm Accountancy Network, 14

E

economic commodity., 110
economic model, 157
economic performance, 19
economic policies, 6
economic structure, 3
economic, 114, 121, 122
ecosystem management, 147
ecosystem, 147
efficiency conversion, 3
efficiency scores, 18
efficiency, 21, 75, 76
elasticities, 73
elasticity, 51, 169
emission
emissions, 6, 27, 191, 202
energy coefficients, 30, 37
energy consumption, 1
energy consumption, 191, 202
energy cost, 202
energy crops, 3
energy efficiency, 41
energy input, 30, 35
energy intensity, 5, 27, 57, 61
energy productivity, 5, 27, 30, 35, 59
energy source, 131
energy storage, 47
energy supply, 3
energy yield, 34
energy, 1, 27, 47, 57, 97, 104, 122, 162, 177
environment, 84, 180, 148, 100
environmental externalities, 231
environmental, 70, 108, 135, 178, 180
equilibrium 59, 165
ethanol, 217
eutrophication, 192
evolution, 70
exogenous, 61
exotic, 149
external analysis, 22

F

Farm Accounting Data Network, 219
farm size, 17
farm land, 122
fertilisation strategy, 5, 23
fertilisation, 82
fiber, 132
firewood, 207
firm size, 47
flexibility, 158
forest management, 135, 141
forest, 135
forestation program, 143
forestation, 154

forestry, 77, 105, 135
fossil energy, 82, 104, 191,192, 194, 205
fossil fuels, 1, 4, 6, 76, 82, 104, 135
fossil, 107, 110
fuels, 110

G

gasfication, 211
gasoline, 218
genotype, 96
Geographic Information System, 6, 121, 122
geographical boundaries, 110
geographical, 105, 157
geometry, 122
geothermal energy, 206
Geothermal, 206
GHG emissions, 218
GHK simulation, 45
giganteus, 87
GIS, 122
globally, 57
glycerine, 112
grain mass, 92
grass, 194
grassland, 194
greenhouse effect, 111
greenhouse, 191
gross margin, 23

H

harvest index, 92
HCl, 111
hemp price, 128
hemp production, 121, 128, 130
Hicks-neutral, 59
high-input, 83
Holstein, 128
homogenous, 127
hybrid poplar plantations, 141
hydroelectric, 160, 168
hydrologic, 158
hydropower plant, 171
hydropower, 145, 158, 160, 157, 161, 168, 206

I

implementation, 4
incineration, 182
income elasticity, 205, 213
indirect energy, 11, 78
industry, 41, 51,73
institutional, 158
integrated farming systems, 28, 38
intensification, 71
intensity analysis, 66
interactive simulation model, 15
interpolation, 53
irreversibility, 53
irrigation efficiency, 166
irrigation season, 169
irrigation, 81

K

Kyoto Protocol, 1, 4, 137, 192
Kyoto, 136, 145, 231

L

labour, 59
landscape, 86
legalization, 121
life cycle, 105

linear homogeneity, 61
linear optimization approach, 123
linear program, 222
Linear Programming Models, 122, 126, 133
livestock manure, 178
livestock production, 186
livestock, 185
logarithmic, 166
Logit model, 50
low-input system, 78, 85
low-input, 84
LP models, 17
LPMs, 122, 126

M

machinery, 37, 50
macro-economic, 200
magnitude, 100
manure, 93
marginal costs, 146
marginal soils, 94
market failure, 135, 138, 139
market price, 223
market share, 137
maturity, 149
maximisation, 43, 171
maximum likelihood, 66
McFadden 50, 58, 66
mean log likelihood function, 50
mechanical, 95
mechanisation, 28, 146
methane, 191, 206
methodology, 57, 65, 219
methyl esters, 218
methyl, 106
micro-economic model, 224
micro-economic, 217
milk quota, 193
Mineral Accounting System, 11
Miscanthus, 87, 89
mitigation, 135
modernisation, 71
moisture content, 90
monoculture, 128, 212
Monte Carlo simulation, 42, 51
Multinomial Logit model, 50
multi-objective programming, 232

N

N_2O-emission, 196
N_2O-N-emissions, 196
natural gas, 145
natural resources, 3
NGOs, 144
NH_3, 111
nitrogen deposition, 78
nitrogen, 78, 192
nitrous oxide, 191
non-artificial nitrogen, 82
nuclear energy, 1

O

obligation, 224
optimisation model, 121, 159
optimum, 157
organic farming, 192
organic nitrogen, 18
organic waste, 178
organic, 179
ozone, 111

P

Pareto sense, 168, 172
Pareto, 158

partial productivity, 65
Partitioning, 95
pasture, 139, 194
pay-off matrix, 233
personal income, 209
pesticide, 128
pests, 93
petroleum gas, 211
phosphorus, 186
photosynthesis, 78, 135, 230
photosynthetic, 89
physiological, 89, 90
physiology, 89
pig, 94, 186
plantation, 136
plough, 32
policy, 134
political conditions, 128
political, 114
pollution, 210
population, 209
potassium, 186
power plant, 131
price ratio, 48
probability functions, 173
probability, 49, 50,149
Probit model, 41, 47, 48
production costs, 123, 182, 219
production function, 60
production system, 79, 90
production, 105
productivity, 89
profit, 162
profitability, 41
proportion, 88

Q

quotas, 123

R

radiation, 77
rain forest, 108
rain, 210
reference system, 108
reforestation strategy, 141
reforestation, 135, 136, 139, 140
renewable energy sources, 1
renewable energy, 87, 147, 205, 212
reservoir, 166
reversibility, 53
RME, 114
rural households, 209
rural, 207

S

Salix viminalis, 87, 90
sanitation, 183
sensitivity analysis, 202
significant, 47
silage, 194
silvicultural, 148
Simulated Maximum Likelihood, 43, 48, 53
simulation model, 14, 77
simulation, 89
slurry, 178
SML method, 42, 50
SO_2, 111
socio-economic, 85, 93
solar energy, 82
solar radiation, 79, 206
Specification, 165
stability, 148
statistical, 90
stem fraction, 99
stem, 96
stochastic, 44
strategic management, 13, 21
stratospheric, 111
straw, 89, 207

subsidy, 123
substitution, 59, 74
sulphur, 192
supply, 29
sustainability, 192
sustainable energy, 1, 39, 135, 205, 214
synthetic, 193

T

technical coefficients, 63, 221
technical efficiency, 17, 18
technical inefficiencies, 12
technical performance, 17
technological change, 7, 59
technology, 41, 166
telecommunication, 206
temperate zones, 4
temperature, 77
terrestrial sinks, 137
theoretical foundation, 59
theoretical justification, 58
theoretical model, 42, 165, 166
thermal energy, 48
threshold price, 128
transaction costs, 142
transformation capacity, 226
transformation costs, 226
transition zone, 141
transition, 2, 136
translog cost function, 60
translog, 59
transportation costs, 131
transportation, 188

U

uncertainty, 37, 53
urbanization, 139

V

variance, 47
variation, 87
variety, 22, 58

W

water, 100
wheat-to-ethanol, 226
wind energy, 206

Y

yield, 22, 97

Reviewers

Abler, D.	Pennsylvania State University, USA
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Kropff, M.	Wageningen University, the Netherlands
Kruseman, G.	Wageningen University, the Netherlands
Londo, M.	Utrecht University, the Netherlands
McCarl, B.	Texas A&M, USA
Moerschner, J.	Institute of Energy Economics and the Rational Use of Energy (IER), University of Stuttgart, Germany
Nonhebel, S.	Groningen University, the Netherlands
Nucifora, A.	University of Catania, Italy
Oskam, A.	Wageningen University, the Netherlands
Peerlings, J.	Wageningen University, the Netherlands
Pietola, K.	Agricultural Economics Research Institute, Finland
Piot, I.	INRA, France
Read, P.	Massey University, New Zealand
Roosen, J.	Université Catholique Louvain-la-Neuve, Belgium

Rose, A.	Pennsylvania State University, USA
Rossing, W.	Wageningen University, the Netherlands
Rozakis, S.	INRA, France
Schrattenholzer, L.	IIASA, Austria
Silva, E.	University of Porto, Portugal
Slangen, L.	Wageningen University, the Netherlands
Smit, B.	Agricultural Economics Research Institute (LEI), the Netherlands
Smulders, J.	Tilburg University, the Netherlands
Steininger, K.	University of Graz, Austria
Van den Broek, R.	Utrecht University, the Netherlands
Van Kooten, K.	University of Nevada, USA
Van Tongeren, F.	Agricultural Economics Research Institute (LEI), the Netherlands
Vleeshouwers, L.	Wageningen University, the Netherlands
Walsh, M.	Oak Ridge National Laboratory, USA
Weikard, H.-P.	Wageningen University, the Netherlands
Wesseler, J.	Wageningen University, the Netherlands
Zhang, Z.X.	East-West Center, USA

Contributing authors

Best, G.	Food and Agriculture Organisation (FAO), Rome, Italy
Bielsa, J.	University of Zaragoza, Spain
Brodersen, C.	University of Kiel, Kiel, Germany
Dalgaard, T.	Danish Institute of Agricultural Sciences , Tjele, Denmark
De Koeijer, TJ.	Agricultural Economics Research Institute (LEI), Wageningen, The Netherlands
Drescher, K.	University of Kiel, Kiel, Germany
Duarte, R.	University of Zaragoza, Spain
Gärtner, S.O.	Institute for Energy and Environmental Research (IFEU), Heidelberg, Germany
Graham, P.J.	University of British Columbia, Vancouver, Canada
Hjort-Gregersen, K.	Danish Institute of Agricultural and Fisheries Economics, Copenhagen, Denmark
Janssens, S.R.M.	Agricultural Economics Research Institute (LEI), Wageningen, The Netherlands
Jungk, N.C.	Institute for Energy and Environmental Research (IFEU), Heidelberg, Germany
Krcmar, E.	University of British Columbia, Vancouver, Canada
Liming, H.	Jinan University, Guangzhou, China
Lücke, W.	Institute for Agricultural Engineering, University of Göttingen, Göttingen, Germany
McNamara, K.	Purdue University, West Lafayette, USA
Millan, J.A.	Polytechnic University of Madrid, Spain
Moerschner, J.	Institute of Energy Economics and the Rational Use of Energy (IER), University of Stuttgart, Germany
Nonhebel, S.	Center for Energy and Environmental Studies (IVEM), University of Groningen, The Netherlands
Oude Lansink, A.	Wageningen University, Wageningen, The Netherlands
Pietola, K.	Agrifood Research Finland, Helsinki, Finland
Reinhardt, G.A.	Institute for Energy and Environmental Research (IFEU), Heidelberg, Germany
Rozakis, S.	INRA-UMR Economic Publique, Grignon, France
Smit, A.B.	Agricultural Economics Research Institute (LEI), Wageningen, The Netherlands
Sourie, J-C.	INRA-UMR Economic Publique, Grignon, France

Van Ierland, E. C.	Wageningen University, Wageningen, The Netherlands
Van Kooten, G.C.	University of Nevada, Reno and Wageningen University, The Netherlands
Vanderpooten, D.	Université Paris IX-Dauphine, France
Vleeshouwers, L.M.	Wageningen University, Wageningen, The Netherlands
Wossink, G.A.A.	North Carolina State University, Raleigh, USA and Wageningen University, The Netherlands

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